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THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at Manson House, 26 Portland Place, London, W.1, on November 29, 1951 with Dr E. B. Evans (*Vice-President*) in the Chair.

THE CHAIRMAN, opening the meeting, said: The paper this evening deals with a subject which has been of very great interest in the petroleum industry for many years. In fact, the subject of viscosity–temperature relationships and the best means of expressing them and comparing them has exercised the attention of investigators ever since lubrication began to be a science rather than merely an art.

This problem, of course, is part of a very much wider problem—the whole problem of the viscosity–temperature relationships of liquids—and even for the most simple liquids we have not, of course, a complete and satisfactory explanation of viscosity–temperature variation. The difficulties of investigating these variations in such complex mixtures as those occurring in petroleum fractions are quite obvious.

Fortunately, in the authors of this paper we have two gentlemen who are very well qualified to grapple with the difficulties involved; both of them have had a very long and varied experience in the petroleum industry.

Mr Blott has two main interests, and most of his published work has been either in the field of bitumen or of rheology. Perhaps his interest in bitumen led to his interest in rheology, for rheological properties are of great importance in the bitumen field.

Mr Verver has been in the petroleum industry for more than thirty years, and he has worked in a number of different fields—in refining, including the treatment of lubricating oils and de-waxing, viscosity, and, I believe, bitumen. Quite a number of his papers have been published in the Institute's *Journal* and will be well known to many of our members.

With their combination of experience and interests over many years, Mr Blott and Mr Verver are very well qualified to discuss this subject.

The following paper was then presented by the authors :—

METHODS FOR EXPRESSING THE VISCOSITY–TEMPERATURE RELATIONSHIP OF LUBRICATING OILS

By J. F. T. BLOTT * (Fellow) and C. G. VERVER † (Fellow)

SUMMARY

Part I reviews indices which have been proposed in the past for expressing, by a single figure, the viscosity–temperature susceptibility of lubricating oils.

The indices are divided into two groups: *non-relative* indices (viz., those based on some function of the slope of the v–T curve, without reference to

* "Shell" Refining & Marketing Co., Central Laboratories, Fulham.
† Koninklijke/Shell-Laboratorium, Amsterdam.

any standard) and *relative* indices, involving a comparison with certain standards of reference. The authors advance the view that only an index of the latter type can be satisfactory in practice. The relative indices proposed so far, however, all have one or more shortcomings.

In Part II the authors propose a relative index, which is a modification of the present Viscosity Index and for which the name *Viscosity Modulus* is suggested. This modulus resembles the present Viscosity Index, but substitutes the logarithms for the plain values of $v_{100°F}$ in the calculation, viz.:—

$$\text{Viscosity Modulus} = 100 \times (\log_{10} L - \log_{10} U)/(\log_{10} L - \log_{10} H)$$

U, L, and H being the kinematic viscosities at 100° F of the oil under test and the two standard series respectively. For the L and H series the use of the values published by Hersh, Fisher, and Fenske is advocated. It is shown that in this manner:

(*a*) The index becomes additive for oils of the same viscosity level but different slope;

(*b*) the index becomes closely related to the functions $1/v \,.\, dv/dT$ and $d \log v/d\,(1/T)$, which have been considered to be of fundamental importance;

(*c*) anomalous values of the index in the case of oils having a high index figure are avoided;

(*d*) the sensitivity of the scale is distributed more evenly; and

(*e*) irregularities, due to the "waviness" of the present reference series, are eliminated.

A method by means of which a figure for the index between any desired temperature limits may be calculated is elaborated.

Introduction

Since 1929 a very large number of methods have been proposed for expressing the characteristic viscosity–temperature behaviour of oils by a single figure. Among the various methods suggested (many of which have found local application) only one has come into universal use: the Viscosity Index system originally proposed by Dean and Davis [1] and later modified by the introduction of new data serving as basis for the calculation.[2, 3] Another mode of expression, the Pole Height method of Ubbelohde and collaborators,[4] has been employed to some extent in Germany and other Central European countries. Whilst the former has considerable merit (more so, in the authors' opinion, than the criticism frequently levelled against it would lead one to believe), both systems suffer from shortcomings which render them unsuitable for certain modern requirements.

Part I of the present paper reviews the various systems and indices which have been proposed in the past and gives the authors' views on their merits.

Part II presents a proposed modification of the present Viscosity Index system, which retains the essential features of the original Dean and Davis scheme while eliminating its anomalies.

PART I—CRITICAL REVIEW OF METHODS

The most convenient classification of the various methods of expression is into "*non-relative*" and "*relative*" indices.

Non-relative, or, as they are sometimes called, "absolute" indices, are expressions giving some derivative of the viscosity–temperature curve, no attempt being made to relate the figure to the properties of known

materials, such as pure compounds or standard series of oils. Mathematically speaking, these indices are functions of the slope of the curve and are frequently of a complicated nature, involving one or more parameters such as temperature or viscosity at a particular temperature.

Relative indices relate the viscosity–temperature characteristics of a given oil to some standard of reference.

Non-relative Indices

A. The simplest expression for the change of viscosity (v) with temperature (T) is the actual slope of the viscosity curve, dv/dT.

However, for a given oil, this slope changes rapidly with T, and it is different at the same temperature for successive members of a series of homologous compounds or for different oil fractions from the same natural source. For this reason, dv/dT has been consistently avoided as a means of characterizing the viscosity–temperature relationship.

In a search for more characteristic forms of non-relative indices, several other expressions constituting more complex functions of dv/dT have been put forward.

The functions $1/v \,.\, dv/dT$ and $1/\eta \,.\, d\eta/dT$, which usually differ but little (v being the kinematic and η the dynamic viscosity), were introduced by Wiggins,[5] and are regarded by Ramser [6] and Göttner [7] as being of fundamental importance. These functions represent the fractional change in viscosity with temperature, and may be expressed as the percentage change in viscosity for a small definite change in temperature. According to various well-known formulæ (as Göttner has pointed out) the coefficient of friction μ in a loaded bearing, at constant speed and load, is directly proportional to some power of η, say to η^x, viz.,

$$\mu = C\eta^x \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(I)}$$

(in which the value of x depends upon the prevailing conditions). If this equation in its logarithmic form

$$\log \mu = \log C + x \log \eta \quad . \quad . \quad . \quad . \quad \text{(II)}$$

is differentiated, we obtain

$$1/\mu \,.\, d\mu/dT = x/\eta \,.\, d\eta/dT \quad . \quad . \quad . \quad . \quad \text{(III)}$$

in other words, the fractional (or percentage) change in coefficient of friction in a bearing, for a given small change in temperature, is proportional to the fractional (or percentage) change in viscosity.

There would appear to be some justification for regarding this fact as important, but in the authors' opinion its significance should not be stressed unduly, since small changes in bearing friction are never quoted as an argument for the use of " steeper " or " flatter " oils. In practice there is more interest in viscosity changes over large temperature intervals. The use of an average value of the function $1/v \,.\, dv/dT$ over a definite temperature interval, as proposed by Ramser, hence seems more logical. It will be discussed later in this paper.

Although the functions $1/\eta \cdot d\eta/dT$ * and $1/v \cdot dv/dT$ for a given oil vary with temperature, their values at a given temperature for the members of a series of oils of the same type are less dependent on the viscosity level than are the values of $d\eta/dT$ or dv/dT. The values of the functions $1/\eta \cdot d\eta/dT$ and $1/v \cdot dv/dT$ also have the merit that they are closely related to the energy of activation of viscous flow, which enters into the fundamental theory of the viscosity of liquids.

Still more closely related to this energy of activation is the function $d \log v/d(1/T)$, which may also be written as $-T^2/v \cdot dv/dT$. This function was discussed by Whalley and Leach.[8] (Graphs with axes graduated in $\log v$ and $1/T$ had previously been used by Kobeko and Shishkin.[9]) The value of this function is less dependent upon temperature than that of $1/v \cdot dv/dT$.

B. With the development of empirical equations giving the relation of viscosity to temperature, various parameters of such equations have been suggested as indices for viscosity–temperature dependence.

The one most frequently used for petroleum oils is the Walther–ASTM equation,[10] sometimes referred to in Russian literature as Nevitt's equation: [11]

$$\log_{10} \log_{10}(v + a) = m \log_{10} T + b \; . \qquad . \qquad . \qquad \text{(IV)}$$

where v = viscosity in centistokes;
T = absolute temperature in degrees Kelvin.

The equation is purely empirical, although it bears some resemblance (after suitable re-arrangement) to equations developed on more fundamental grounds. It is generally assumed that, for a particular oil, m, b, and a may be taken as constants and that a may, without serious error, be given a definite value valid for all petroleum oils. In the latest edition of the ASTM Viscosity–Temperature Chart † (ASTM D 341–45), which has axes graduated in proportion to log log $(v + a)$ and log T, a value of a equal to 0·6 is employed for all viscosities down to 1·5 cs.‡ With m, b, and a constant for a particular oil, the equation is linear on this chart, and m represents the slope, viz., the tangent of the angle with respect to the log T axis.

The practical value of m lies in the fact that it enables the viscosity to

---

* As a practical form of $1/\eta \cdot d\eta/dT$, Göttner proposed the expression:—

$$-\frac{1000}{2{\cdot}303} \cdot \frac{d \log_e \eta}{dT} = -\frac{1000}{2{\cdot}303\eta} \cdot \frac{d\eta}{dT}$$

to which he gives the name: *Viscosity–Temperature Modulus.*

† The first chart giving a rectilinear relationship between viscosity and temperature was published by McCoull,[12] but the publication does not mention the equation on which this chart was based.

‡ One of the authors has recently carried out a check on the Walther–ASTM formula by accurate viscosity determinations on a number of oils over a wide temperature range. A definite lack of agreement (viz., a lack of constancy in a), falling well outside the experimental error, came to light. The magnitude of the errors was such, however, that the formula may be considered of sufficient accuracy for viscosity measurements of normal precision, provided it is not used for extreme cases of extrapolation. Over the whole of the range studied (−16° to 150° C) the best compromise for the value of a for mineral oils, to one place of decimals, was not 0·6 (or 0·8 as previously assumed) but 0·7. It is intended to publish the observations at some future date.

be obtained at any desired temperature, if b is known, by simple calculation or graphical means, and that the two parameters b and m can be deduced from two viscosity observations only. m is independent of temperature, but varies considerably with the viscosity in oil series prepared from the same base material.

Numerous proposals have been made to use m, or some function of m only, as an index for the viscosity–temperature relationship. These proposals may conveniently be treated together.*

B. 1. Walther [10] in 1933 suggested quoting m itself.

B. 2. Bell and Sharp [13] proposed determining the slope of the straight line drawn for a particular oil on the former ASTM chart D by measuring the vertical and horizontal co-ordinates with the aid of linear scales superimposed on the viscosity and temperature scales respectively. The horizontal (K) scale was so graduated that K had a value of 0 at 210° F and of 1 at 100° F; its equation is found to correspond with :—

$$K = -12{\cdot}825 \log T + 32{\cdot}97 \quad . \quad . \quad . \quad \text{(V)}$$

(T in degrees Kelvin)

whilst the vertical (H) scale, according to Hirschler,[17] was in accordance with the relation

$$H = 870 \log \log (v + a) + 154 \quad . \quad . \quad \text{(VI)}$$

From the values H_1 and H_2 read off at two viscosities equivalent to K_1 and K_2, the "*Viscosity Slope Factor*" was found by the formula :

$$\text{V.S.F} = (H_1 - H_2)/(K_1 - K_2) \quad . \quad . \quad . \quad \text{(VII)}$$

(Hirschler [17] later revised Bell and Sharp's tables of H, which were given in Saybolt Universal units, for the new charts D 341–39 C/D and the ASTM new conversion factors to kinematic viscosities).

From formulæ (V) and (VI) it may be shown that

$$m = -0{\cdot}0780 \times \text{V.S.F.} \quad . \quad . \quad . \quad \text{(VIII)}$$

B. 3. Whitmore, Fenske (of Pennsylvania State College), and others in the U.S.A.[14] calculated the slope by measuring the vertical and horizontal increments on ASTM chart D in millimetres and determining their quotient, which, if the temperatures are 100° and 210° F, becomes :

$$\text{(mm vertically between visc at 100° and 210° F)}/111 \quad . \quad \text{(IX)}$$

Since the modulus of the horizontal scale is five times that of the vertical scale, the "*Pennsylvania State Slope Number*" was related to m by the formula

$$m = -5 \times \text{P.S.S.N.} \quad . \quad . \quad . \quad \text{(X)}$$

B. 4. Pinkevitch [11] defined the slope as equal to

$$1000 \times [\log \log (v_{50^\circ\text{C}} + 0{\cdot}8) - \log \log (v_{100^\circ\text{C}} + 0{\cdot}8)] \quad . \quad \text{(XI)}$$

His slope number, referred to as the "*Viscosity Temperature Coefficient*," is given by

$$m = -0{\cdot}01600 \times \text{V.T.K.} \quad . \quad . \quad . \quad \text{(XII)}$$

* Changes in value of the constant a in the Walther–ASTM formula will be disregarded.

B. 5. Clayden [15] proposed the following way of expressing the slope. On the ASTM chart the line for the oil in question is plotted; a straight line is then drawn parallel to it through the point (10,000 cs, 0° C) and the viscosity at which this line intersects the ordinate of 100° C is read off. This value is termed the "*Viscosity Gradient.*"

Calculation shows that

$$m = [\log \log (\text{V.G.} + a) - 0{\cdot}6021]/0{\cdot}1356 \quad . \quad . \quad \text{(XIII)}$$

C. Several proposals have been made in which an index is derived from two more or less arbitrary points on the v–T curve.

In a recent paper, Sanderson [16] expressed the v–T relationship in terms of the temperature span in degrees Fahrenheit (referred to as the "*Viscosity Temperature Number*") between any two selected viscosities (x and y cs) for the oil in question. Thus:—

$$\text{V.T.N.} = {}^{\circ}\text{F}_{(x\text{ cs})} - {}^{\circ}\text{F}_{(y\text{ cs})} \quad . \quad . \quad . \quad \text{(XIV)}$$

Sanderson suggested 5 and 100 cs as generally suitable viscosities for x and y.

The V.T.N. has the disadvantage that it increases rapidly with the viscosity level in oil series of the same type.

Ramser [6] has proposed using the average value of $1/v \,.\, dv/dT$ over an arbitrary temperature range as the basis of a non-relative index. The average value of this expression between temperatures t_1 and t_2 becomes

$$2{\cdot}303 \log_{10} (v_2/v_1)/(t_2 - t_1). \quad . \quad . \quad \text{(XV)}$$

(This quantity has a negative value, and Ramser has suggested multiplying it by a factor of -100 to give what he terms the "*Viscosity–Temperature Rating.*") In a similar manner, it would be possible to derive an average value of the function $d \log v/d(1/T)$ proposed by Whalley and Leach,[8] and this would lead to the expression

$$2{\cdot}303 \log_{10} (v_1/v_2) \,.\, t_1 t_2/(t_2 - t_1) \quad . \quad . \quad \text{(XVI)}$$

Though the V.T.R. and the equivalent average value of $d \log v/d(1/T)$ suffer from the inherent disadvantages of all non-relative indices, the authors consider that their close relation to the fundamental theory of viscous flow renders them the most significant measures of temperature susceptibility in this group.

Discussion of the Non-relative Indices

A consideration of the proposals referred to above gives rise to the following comments.

In practice, where there is in general a certain optimum viscosity level for the oil used in any particular application, a greater absolute change in viscosity, over the temperature range concerned, may normally be tolerated as the viscosity level is higher. A satisfactory index of viscosity–temperature characteristics should therefore take into account the effect of the viscosity level of the oil on the change of viscosity with temperature.

Of the non-relative indices discussed above, the V.T.N. bears no direct mathematical relationship to viscosity level, but the various expressions

of m from the Walther formula and the indices based on $1/\eta \,.\, d\eta/dT$, $1/v \,.\, dv/dT$, and $d \log v/d(1/T)$ are related to this factor directly in some mathematical form. However, from the point of view of a practical index, neither the m value nor the differential functions (including the Viscosity–Temperature Rating proposed by Ramser and the corresponding expression to be derived from the Whalley and Leach function) makes full allowance for viscosity level, in the sense that the indices based on them still vary considerably for members of different viscosities in a series of oils of the same type.

In reading the various papers referred to above the authors have noted the fact that much of the reasoning offered in support of any particular index implies a very general acceptance of the idea that natural petroleum oils constitute a family, each member of which consists of a series of fractions showing a certain regularity in chemical structure, and that the members of each series may be compared as having the same qualitative viscosity–temperature characteristics. There is usually some reference in the paper to the relation between the proposed index and the best-known of the relative indices (*e.g.*, the Dean and Davis V.I. or the Ubbelohde–Walther " Pole Height "). For example, one of the supporters of the ASTM slope (the m-function) states (illustrating his claim with a table) that the slope is " roughly " parallel to V.I. : an incorrect statement in this case, since the variability of m with viscosity is the basis of the " Pole Height " method.

According to the above-mentioned criterion that a viscosity–temperature index should take into account the effect of viscosity level, none of the non-relative indices discussed above is suitable for adoption in the form in which it has been presented. This conclusion does not preclude the possibility, however, that certain of them might be used as the basis of a more comprehensive scheme which will satisfy practical requirements.

It should be mentioned at this point that, in principle, the n value derived by Hardiman and Nissan [19] satisfies the above requirements. Since, however, these authors proposed to use their n value as a basis of a relative index, their system is discussed in the next section.

Relative Indices

1. *The Viscosity-Index System*

The first relative system to be put forward was the " Viscosity Index " of Dean and Davis, published in 1929.[1] It constitutes a comparison between the viscosities of the oil at 100° F and the viscosities (also at 100° F) of oils from two standard series, all three oils having the same viscosity at 210° F. The two reference series were oils derived respectively from a base stock giving lubricants with very flat curves (the H series, reputed to be Pennsylvanian oils) and from a base stock giving " steep " oils (the L series, said to be based on a certain Gulf Coastal crude). The Viscosity Index is calculated by a simple interpolation, in per cent, of the viscosity at 100° F of the oil under test (U) between the corresponding viscosities of the H and L oils :

$$\text{V.I.} = 100 \,.\, (L - U)/(L - H) \quad . \quad . \quad \text{(XVII)}$$

An oil in the *H* series hence always had a V.I. of +100, and an oil in the *L* series a V.I. of 0.

At the time of publication few lubricants had a V.I. higher than +100. On the other hand, negative V.I.s were fairly common; several highly aromatic and naphthenic Indonesian crude oils, for instance, give lubricants with values of −100 to −300.

The original tables for the *H* and *L* series were given by Dean and Davis in Saybolt Universal seconds for the range of 40 to 160 sec, and were each represented by a single equation :—

$$y = 0{\cdot}0408\,x^2 + 12{\cdot}568\,x - 475{\cdot}4 \quad . \quad . \quad \text{(XVIII)}$$

for the *H* series and

$$y = 0{\cdot}216\,x^2 + 12{\cdot}07\,x - 721{\cdot}2 \quad . \quad . \quad \text{(XIX)}$$

for the *L* series (x = S.U.S. at 210° F, y = S.U.S. at 100° F).

In 1932 Davis, Lapeyrouse, and Dean [2] revised these tables for the range 40 to 50 S.U.S. at 210° F, since measurements with modified Ostwald viscometers had revealed inconsistencies.

In view of the tendency towards the adoption of kinematic units of viscosity and the use of viscometers of greater accuracy in the oil industry, Hersh, Fisher, and Fenske [18] published a table in 1935 for the calculation of "kinematic" Viscosity Index values (K.V.I.) from observations in centistokes in the range from 2·5 to 100 cs. The data were based on viscosity measurements of cuts from Pennsylvanian oils prepared by Hersh, Fisher, and Fenske themselves and on the data of Davis, Lapeyrouse, and Dean; the 0 V.I. series was based entirely on the figures of the latter authors. (The factors used to convert S.U.S. to centistokes were not stated.) It was found that the two series could be adequately described over the whole range by a single formula in each case, viz :—

$$\text{100 K.V.I. series :} \quad v_{100} = 2{\cdot}808\,(v_{210} - 0{\cdot}500/v_{210}{}^{1{\cdot}33})^{1{\cdot}5} \quad . \quad \text{(XX)}$$

$$\text{0 K.V.I. series :} \quad v_{100} = 2{\cdot}450\,(v_{210} - 0{\cdot}213/v_{210}{}^{1{\cdot}08})^{1{\cdot}8} \quad . \quad \text{(XXI)}$$

Though widely used in a number of laboratories (*e.g.*, in those of the Royal Dutch/Shell Group, where they were considered satisfactory), Hersh, Fisher, and Fenske's tables were never standardized by the ASTM.

In 1940 Dean, Bauer, and Berglund [3] published another table for calculating V.I. from kinematic viscosities, no reference being made to the publication of Hersh, Fisher, and Fenske.

This table became an ASTM standard in 1941 (D 567–41), and an IP standard in 1947 (IP 73/47).

The range of this table (2 to 75 cs at 210° F) is not covered by a single equation; instead, three sections are to be distinguished :—

(*a*) a section above 7·30 cs at 210° F, which was based on Dean and Davis' formulæ (XVIII) and (XIX);

(*b*) a section of low viscosities from 2·0 to 3·99 cs at 210° F, for which the following formulæ were used—

$$y = 1{\cdot}4825\,x + 0{\cdot}91375\,x^2 \text{ (}H\text{ series)} \quad . \quad . \quad . \quad \text{(XXII)}$$

$$y = 1{\cdot}655\,x + 1{\cdot}2626\,x^2 \text{ (}L\text{ series)} \quad . \quad . \quad . \quad \text{(XXIII)}$$

(*c*) a section of intermediate viscosities, in which " the *H* and *L* values were obtained by a special method of calculation equivalent to graphic interpolation. . . . In this range of viscosity the constants are not defined by equations." [3]

The V.I. system has been very widely employed. It has also been much criticized, partly on the grounds of its being entirely empirical and not sufficiently " fundamental," partly owing to certain defects which it possesses, especially when used outside the field for which it was originally intended.

The V.I. has the very great merit of being the first method of expressing, by a single figure, the *relative* viscosity–temperature behaviour of an oil. Dean and Davis, in their original article, also stated that the V.I. was a characteristic constant of the base material. Actually, the V.I.s of lubricating-oil fractions from one oil may vary somewhat with their viscosity, but in a general sense the V.I. has a definite relation to chemical structure * and, on the whole takes complete account of what may be called the " natural homology " occurring in lubricating-oil series.

The main real objections against the Viscosity Index, in the authors' opinion, are the following, which have already been mentioned in various publications :—

(*a*) Owing to the nature of the relationship between $v_{210^\circ F}$ and $v_{100^\circ F}$ of the basic standard series and the method of calculating the index, anomalous results are obtained at V.I. values considerably above +100. The curve relating $v_{100^\circ F}$ to $v_{210^\circ F}$ for oils having a V.I. of more than about +140 reaches a maximum value of $v_{100^\circ F}$, so that two oils having the same $v_{100^\circ F}$ but widely different values of $v_{210^\circ F}$ may have the same V.I. (see Fig 6).

Whilst this objection had no practical significance at the time of Dean and Davis' publication, it has become a very real objection now that lubricants of non-hydrocarbon types have entered the field. This fact may be illustrated by the figures in Table I, encountered in laboratory practice :—

TABLE I

Lubricant	$v_{210^\circ F}$, cs	$v_{100^\circ F}$, cs	V.I. (ASTM D 567–41; IP 73/47)
Ester type . . .	16·6	89·7	+148
Silicone type . . .	38·6	90·9	+150½

It will be seen that these two lubricants have nearly the same V.I. and viscosity at 100° F, but that the silicone has more than twice the viscosity of the ester at 210° F.

Viscosity Indices of this magnitude and higher are hence meaningless.

(*b*) The Viscosity Index is derived from the viscosities at two set temperatures, 100° and 210° F. In the case of normal petroleum oils it may

* A method for predicting the V.I. of saturated oils from the " ring " analysis was published by Van Westen, Leendertse, Vlugter, and Waterman.[23]

be assumed that the Walther formula holds over a wide temperature range with sufficient accuracy. The viscosities at other temperatures can then be calculated or determined graphically. The V.I. in such cases gives a sufficient indication of the relative v–T relationship.*

However, many "abnormal" oils (particularly non-hydrocarbon lubricants) do not comply with the Walther formula over a wide range. Their graphs on the ASTM chart are curved, and the V.I. determined between 210° and 100° F then gives no indication of their behaviour in other temperature ranges.

It is very desirable that a method should be available for expressing a relative v–T relationship in any temperature range.

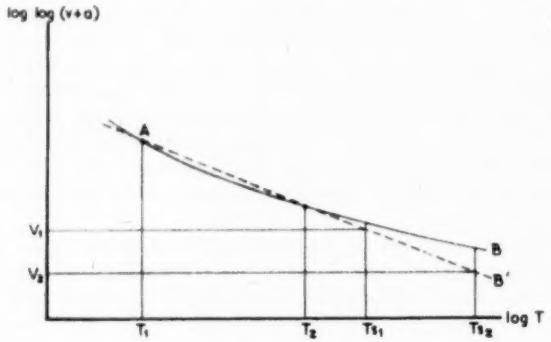

FIG 1

At this stage it may be pointed out that such a method is available in the following device (see Fig 1), which, incidentally, may be applied to any of the proposed relative systems.†

Let AB be the curve for the oil under test on a chart such as that of the ASTM. Let T_1 and T_2 be the temperatures for which the index is to be calculated. Now compare the oil with another oil (AB') having the same viscosities at T_1 and T_2, but complying with the Walther formula. Determine the viscosities v_1 and v_2 which this latter oil would have at the standard temperatures Ts_1 and Ts_2, either by calculation or graphical construction, and calculate the index in the usual way.‡

In this manner it is possible to quote, say, a value of the Viscosity Index in the form $[\text{V.I.}]^{t_1}_{t_2}$, where t_1 and t_2 are the two temperatures to which the index is intended to apply. In the case of an oil complying with Walther's formula the value of this expression will be independent of t_1 and t_2, but in the case of a non-hydrocarbon oil very significant differences may be found. Examples of such expressions will be given later.

* Graphs for determining the V.I. from viscosity observations at pairs of temperatures more customary in Europe than 100° and 210° F (viz., 100°–200° F and 50°–100° C) have been published by Docksey, Hands, and Hayward.[21] These graphs also apply only to oils agreeing with the Walther formula.

† The method was suggested, but not described in detail, in a paper by Tadayon, Hardiman, and Nissan.[20]

‡ Graphical constructions of this kind may also be carried out by means of a nomograph with parallel scales, of the type first proposed for this purpose by Groff.[26]

(*c*) The basic curves of the present V.I. tables, as already stated, do not correspond with a single formula in each case, but consist of three distinct sections. This fact is reflected in erratic variations in the V.I. of oil series, particularly at low viscosities, and as breaks or waves in most graphs relating the V.I. to other properties. Fig 2 is a parallel-scale point nomograph showing lines of constant V.I., in which the waves are very apparent.

Obviously, this is a defect in the system, since it vitiates the parallelism between V.I. and the " natural homology " already referred to.

(*d*) The V.I. scale is more sensitive at its lower than its upper end,* viz., the difference between 0 and +10 on the V.I. scale is far less significant than the difference between +90 and +100.

(*e*) V.I. is not an additive function. Examples will be given in Part II, where the phenomenon will be discussed more fully. It is due to the fact that viscosity is itself not an additive function, and to the method of calculating the V.I.

2. *The " Zero Viscosity Factor "*

In 1934 McCluer and Fenske [23] proposed a relative index (referred to as the " *Zero Viscosity Factor* "), involving a comparison with but a single standard series. This series (presumably of Pennsylvanian origin) was defined by the following formula inter-relating the kinematic viscosities at 100° and 210° F :—

$$\log \nu_{100} = 1{\cdot}502 \log \nu_{210} + 0{\cdot}4400 \quad . \quad . \quad \text{(XXIV)}$$

An oil was chosen from this series so that it had the same viscosity at 210° F as the oil under test. The viscosity at 0° F (−17·8° C) of both oils was then determined : that of the standard oil, $(\nu_0)_s$, by extrapolation with the aid of the Walther–ASTM formula (IV, $a = 0{\cdot}8$), that of the oil under test $(\nu_0)_u$ by direct determination or extrapolation. The Zero Viscosity Factor is the ratio $(\nu_0)_u : (\nu_0)_s$.

A Z.V.F. of 1·0 always corresponds to a V.I. (Dean and Davis) of +99 to +101, but at other values of the V.I. the two indices do not run parallel. (At 5 cs/210° F, a Z.V.F. of 4 corresponds to a V.I. of +25, at 40 cs/210° F, to a V.I. of +77.)

The choice of this index is due to the fact that 0° F is a commonly occurring low winter temperature in the U.S.A. The starting torque of an engine is roughly proportional to the viscosity of the crankcase oil, and the Z.V.F. hence gives an idea of the relative torque at this temperature with respect to a Pennsylvanian oil.

The present authors consider the method to have the following defects :—

0° F is an arbitrary choice. At other temperatures the ratio will be different.

The Z.V.F. is not even approximately constant for a natural oil series.

The calculation would seem to be unnecessarily laborious.

* This objection is to some extent dealt with in a proposal of Larson and Schwaderer [27] to split up the V.I. field into " zones " numbered from 0 (100 V.I.) to 8 (0 V.I.). Obviously this suggestion does not affect the principle of the Viscosity Index system.

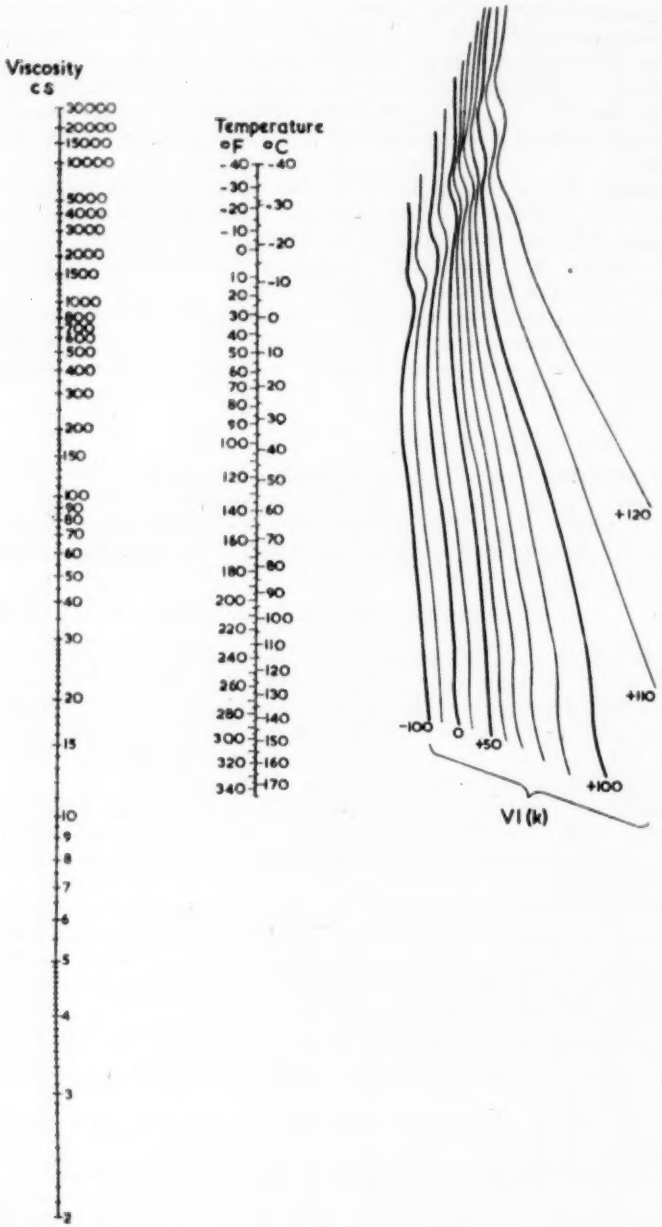
Viscosity
c S
30000
20000
15000
10000
5000
4000
3000
2000
1500
1000
800
700
600
500
400
300
200
150
100
90
80
70
60
50
40
30
20
15
10
9
8
7
6
5
4
3
2
Temperature
°F °C
-40 -40
-30
-20 -30
-10
0 -20
10 -10
20
30 0
40
50 10
60
70 20
80
90 30
100 40
120 50
140 60
160 70
180 80
200 90
220 100
240 110
260 120
280 130
300 140
320 150
340 160
170
+120
+110
-100
0
+50
+100
VI (k)

Fig 2

3. *The " Viscosity Pole Height "*

This method, which was developed in collaboration by Ubbelohde, Walther, and Kemmler,[4] has been fairly extensively used in Germany and other Central European countries.

It is based on the assumption that the v–T lines for lubricating-oil fractions from one crude oil, when plotted against scales of log log $(v + 0{\cdot}8)$ and log T, form a fan or pencil of straight lines, emanating from a single point corresponding with a very low temperature (Fig 3). This point is referred to as the viscosity pole, and its ordinate $W_p = \log \log (v_p + 0{\cdot}8)$ as the " Viskositätspolhöhe " or *viscosity pole height*. The pole height was observed to be greater in magnitude for series of " steep " oils than for series of " flat " oils, and was used as a measure of the relative " steepness " pertaining to oils prepared from the base stock in question.

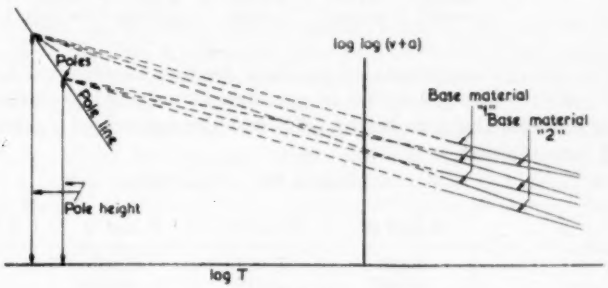

FIG 3

A determination by absolute means requires at least two viscosities at different temperatures for each of two lubricating-oil cuts from the same base material. The originators, however, stated that all viscosity poles lie on a line (known as the " pole line," see Fig 3) having the equation

$$\log T_p = 2{\cdot}410 - 0{\cdot}194\ W_p \quad . \quad . \quad . \quad \text{(XXV)}$$

By assuming this to be true, it is possible to calculate the pole height by solving the Walther equation for the oil under test against equation (XXV). The rather tedious calculation involved may be avoided by a graphical construction developed by Ubbelohde, employing a viscosity chart similar to that of the ASTM and a specially graduated transparent triangle. (The construction has been somewhat simplified in a later edition of Ubbelohde's book.) The graphical procedure is the one which is always followed in practice.

The " viscosity poles," as already stated, are situated at very low temperatures; an extrapolation of such an extreme character almost certainly has no real physical significance. The authors' chief objection against the method, however, lies in the fact that the original assumption (viz., the convergence of lines for the fractions in a series of oils to a single point) generally agrees but very poorly with observed data, particularly if series of oils covering a wide viscosity range are considered.

Thus, taking two sets of three oils ($v_{210} = 2{\cdot}5$, 15, and 75 cs) from Hersh,

Fisher, and Fenske's +100 and 0 K.V.I. series,[18] which are probably among the most reliable data for oil series, and calculating the constants m and b in the Walther equation

$$\log \log (v + 0{\cdot}8) = m \log T + b \quad . \quad . \quad . \quad \text{(XXVI)}$$

the figures in Table II are found.

TABLE II

K.V.I.:	+100			0		
Oil:	A	B	C	P	Q	R
$v_{210°F}$ (cs)	2·5	15	75	2·5	15	75
$v_{100°F}$ (cs)	10·13	162·9	1824	12·03	320·3	5811
m	3·8695	3·4180	3·0691	4·2307	4·1091	3·8681
b	9·6607	8·8644	8·1630	10·5894	10·2168	12·3847

If the points of intersection of the lines are now determined for oils A and B, B and C, P and Q, Q and R respectively by solving the corresponding equations in pairs, the pole height (W_p) and the equivalent value of T_p in Table III are obtained.

TABLE III

Oils:	A and B	B and C	P and Q	Q and R
W_p	2·836	1·993	12·385	3·408
$\log T_p$	1·7637	2·0103	− 0·4244	1·7602
T_p (° K)	58·0	102·4	0·376	57·6

According to Ubbelohde the values of W_p and T_p in the first and second and in the third and fourth columns respectively should be identical, but it will be seen that large differences occur.

Other sets of basic viscosities and actual laboratory observations on various oil series give similar discrepancies, the intersection of low viscosities being generally at a lower temperature than that of higher viscosities. The use of 0·7 or 0·6 instead of 0·8 for the constant a gives a slightly better agreement, but considerable differences are still found.

In view of this lack of precision in the basis of the system, the authors consider it to be artificial and unsatisfactory.

4. *The "Independent Viscosity Index" System*

A modification of the Dean and Davis system, referred to as the *Independent Viscosity Index*, was proposed in 1937 by Malschaert [22] in an attempt to eliminate objections (*a*) and (*b*) referred to in the discussion of the Viscosity Index. It will be shown below that the consequent independence of V.I. from the temperatures of observation (to which the above name is due) is but partial.

The method of calculation is similar to that used for the V.I., but instead of carrying out the interpolation with the viscosities at 100° F it is performed with their Walther functions, viz., $W = \log \log (v + 0{\cdot}8)$:—

$$\text{I.V.I.} = 100 \,.\, (W_L - W_U)/(W_L - W_H) \quad . \quad . \quad \text{(XXVII)}$$

Oils having V.I.s of 0 and +100 obviously also give I.V.I.s of 0 and +100 respectively, if the same basic series are employed. Table IV below shows the values of the I.V.I. corresponding to V.I.s of +50 and −100 at different viscosity levels.

TABLE IV

V.I. (I.P. 73/47)	I.V.I. (Malschaert) based on present V.I. tables		
	$v_{210} = 2$ cs	$v_{210} = 10$ cs	$v_{210} = 75$ cs
+100	+100	+100	+100
+ 50	+ 46	+ 41	+ 34
0	0	0	0
−100	− 75½	− 56½	− 39½

In the case of viscosity indices higher than +100, the value of the I.V.I. rapidly becomes much larger than that of the V.I., but no ambiguous values are encountered within the range of practical interest. The ester and silicone lubricants referred to in Table I, both giving a V.I. of about +150, have I.V.I. values of +215 and +356 respectively. The scale is less sensitive at the low end and more sensitive at the high end than that of the V.I.; this meets objection (*d*) referred to in the discussion of the Viscosity Index.

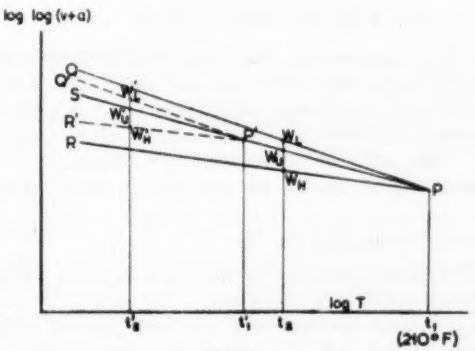

FIG 4

As regards the claimed independence of the I.V.I. from the temperatures of observation, the following remarks may be made.

If, in the Malschaert system, the oil under test is compared with two standard oils having the same kinematic viscosity (or W-function) at, say, 210° F, the second reference temperature may be chosen arbitrarily, since the two reference oils (see Fig 4) are represented on the ASTM chart by straight lines PQ and PR, and hence (if the oil under test also corresponds to a straight line, PS) the ratio $(W_L - W_U) : (W_L - W_H)$ will be independent of the position of t_2. This, however, will in general not be true if the first reference temperature is changed, say to t_1', since lines for the fractions in one series of oils have a different m value (viz., $P'Q'$ is not

parallel to PQ, nor $P'R'$ to PR) so that the ratio $(W_{L'} - W_{U'}) : (W_{L'} - W_{H'})$ is not necessarily the same as $(W_L - W_U) : (W_L - W_H)$.

The I.V.I. is therefore only independent of temperature in a one-sided sense. The $[\text{I.V.I.}]_{100°\,F}^{210°\,F}$ of a natural mineral oil—to use the previous notation—should be equal to the $[\text{I.V.I.}]_{-40°\,F}^{210°\,F}$, but it would not be equal to the figure over a range having another upper limit, say $[\text{I.V.I.}]_{-50°\,C}^{0°\,C}$. The scheme is therefore not capable of giving a satisfactory index figure for an " abnormal " oil over any temperature range which may be desired but only over ranges having one standard temperature as upper limit.

It is obvious, moreover, that each second reference temperature would require separate tables, so that the system would be rather cumbersome.

5. *The " Oil Type Constant "*

Rumpf [24] in 1943 showed that if the directional parameter m in the Walther–ASTM equation is plotted for oil fractions from the same base material against the logarithm of the viscosity at some arbitrary temperature, say 50° C, slanting straight lines are obtained of the type

$$-m = A - 0{\cdot}4 \log v_{50} \quad . \quad . \quad \text{(XXVIII)}$$

viz., lines which are parallel but at different levels. A is hence a value characteristic of an oil series, and Rumpf proposed using it as the basis of an index. For some unspecified reason A itself was not proposed as the index, but a linear function τ of A so as to give

$$\tau = 4 \log v_{50} + (46 - 10\,m) \quad . \quad . \quad \text{(XXIX)}$$

The method has, apparently, not been further elaborated. It seems sound in principle, but a little reflection will show that it actually achieves the same as the V.I. (or Hardiman and Nissan's R.V.I.), viz., the " rectification " of petroleum oil series and the expression of steepness by a single relative figure. The authors cannot see any advantages in it with respect to these systems. Furthermore, the calculation seems rather elaborate.

6. *The " Rational Viscosity Index "*

In 1945 Hardiman and Nissan [19] published a paper in which a rationalized basis for a relative index was proposed.

Hardiman and Nissan showed that the basic figures of the present V.I. system, viz., the 0 and 100 V.I. series of Dean, Bauer, and Berglund,[3] could (at all events from 8 cs upwards) be represented to a close degree of approximation by equations of the type :—

$$v_{100°\,F} = k\,(v_{210°\,F})^n \quad . \quad . \quad . \quad . \quad \text{(XXX)}$$

which when written in logarithmic form becomes

$$\log v_{100} = \log k + n \log v_{210} \quad . \quad . \quad . \quad \text{(XXXI)}$$

Expressions of the same form were found to agree to a satisfactory extent for oil series having intermediate values of the Viscosity Index.

Exponential or logarithmic standard series of the above type are not new (compare equation (XXIV)). Hardiman and Nissan observed, however, that k in the above equations may be given a constant value for

all V.I. series between 0 and +100. The values of v_{210} and v_{100} are hence related by a very simple function of but a single parameter and this parameter n may be used as the basis of a relative index of "steepness."

In the paper referred to, Hardiman and Nissan stated on theoretical grounds that the constancy of k with variations in steepness should hold generally for any two temperatures. Calculations, however, show that this is not the case. In a second publication, Tadayon, Hardiman, and Nissan [20] admitted this fact. Actually, the constancy of k is a fortuitous circumstance valid only for 210° and 100° F; this, however, does not detract from the value of the observation.

If, in equation (XXX) or (XXXI), $v_{210} = 1$ cs is substituted, v_{100} becomes equal to k. In other words, on plotting log v_{100} against log v_{210} with n as parameter a pencil of straight lines emanating from the point (log $v_{210} = 0$, log v_{100} = log k) (Fig 5) is obtained, a circumstance essential to the method, since it eliminates the parameter k.

This fact, however, also gives rise to an anomaly in the system. It

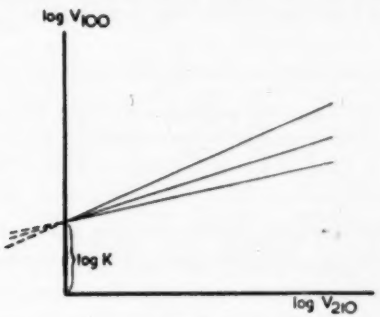

FIG 5

means that oils having a viscosity of 1 cs at 210° F but different values of n would all have the same viscosity at 100° F. In other words, for 1 cs/210° F, differences in n do not correspond to differences in slope. At viscosities lower than $v_{210} = 1$ the steepness would be reversed. Since this does not correspond with actual fact, it is necessary to fix a lower limit to the values of v_{210} for which the system is suitable.

It may be observed in passing that expression (XXXI) does not fit all sets of basic data encountered in literature. Hersh, Fisher, and Fenske [18] also give a logarithmic plot for v_{100} against v_{210}. The lines for their standard series show a noticeable curvature at the lower end. Their formulæ ((XX) and (XXI)) are of exponential type, similar to (XXXI), but contain a term which gives the line the requisite bend.

Hardiman and Nissan assigned the value 0·4336 to log k and found the corresponding values of n to be 1·511 and 1·778 for the "high" and "low" basic lines respectively.

Below 8 cs at 210° F their equations, with these constants, give considerable differences from Dean, Bauer, and Berglund's data, falling well outside the "waves" characteristic of these series. As this is the most sensitive end of the scale (viz., the part where differences in viscosity have

the greatest effect) it would seem that a series based on Hardiman and Nissan's equation and the constants mentioned above are not entirely satisfactory.

Whilst the use of n as a characteristic index would solve difficulties (*a*) and (*c*) referred to in the discussion of the viscosity index, it has a drawback of a psychological nature. To those accustomed to a scale in which 0 is "low" and +100 "high," an index giving values such as 1·623 or 1·814 would probably appear strange and "uncharacteristic."

Hardiman and Nissan consequently devised a formula, by means of which their n could be converted to a figure (called the *Rational Viscosity Index*), correlating fairly closely with the V.I. between 0 and +100 in the range above 8 cs/210° F. The formula was

$$\text{R.V.I.} = (60{\cdot}0 - \text{antilog } n) \times 3{\cdot}63 \quad . \quad . \quad \text{(XXXII)}$$

Hardiman and Nissan gave tables showing a comparison between the V.I. and the R.V.I. for viscosities between 2 and 40 cs and V.I. values of 0 to +100.

At low viscosities the correlation was unsatisfactory, as seen from the figures in Table V.

TABLE V

v_{210}, cs	V.I.	R.V.I.	V.I.	R.V.I.
2	0	65½	100	147½
3	0	61½	100	125

The authors of the present article consider the conversion by formula (XXXII) to be arbitrary, and consequently they cannot regard the R.V.I. system as satisfactory.

7. *The "Paraffin Proportion," "Paraffin Relation," and "Normal Oil Relation"*

Göttner,[7] who, as previously stated, advocated the use of a non-relative index based on the function

$$1/\eta_i \,.\, d\eta_i/dT \text{ or } 1/v \,.\, dv/dT \quad . \quad \text{(XXXIII, XXXIV)}$$

saw the need for converting his unit (the Viscosity–Temperature Modulus) into a relative figure, and proposed no less than three different indices.

The "*Paraffin Proportion*" and "*Paraffin Relation*" are the ratios of the V.T. Modulus of the liquid under test to the V.T. Modulus of an equiviscous member of the paraffin series, both at the same temperature, calculated with the dynamic and kinematic viscosities respectively, and multiplied by 10.

Since the normal paraffins have but a limited range of suitability as a reference series, Göttner proposed a third relative figure, which is ten times the ratio of the V.T. Modulus to that of an equiviscous member of a standard oil series, defined by the equation *

$$m = 4{\cdot}3 - 0{\cdot}43 \log v_{50°\,\mathrm{C}} \quad . \quad . \quad \text{(XXXV)}$$

This ratio is called the "*Normal Oil Relation*."

* Compare "Oil Type Constant," *ante*.

8. *The "Relative Viscosity–Temperature Number"*

Sanderson,[25] the originator of the "Viscosity–Temperature Number" already described, also felt the need for converting this into a relative index. For this purpose, again, a single standard series was employed, in this case, however, not a petroleum series, but one formed by the pure compounds described in literature with the "flattest" v–T curves, viz., the limiting maximum curve on a plot of the V.T.N. (5/100) against viscosity at 210° F. This curve was defined by the equation

$$\text{Standard V.T.N. (5/100)} = 99{\cdot}2 \log v_{210} + 108{\cdot}8 \quad . \quad . \quad \text{(XXXVI)}$$

and the "*Relative V.T.N.*" is given by

$$\text{R.V.T.N.} = 100 \cdot \frac{\text{observed V.T.N. (5/100)}}{\text{standard V.T.N. (5/100)}} \quad . \quad \text{(XXXVII)}$$

The R.V.T.N. is not parallel to the V.I. and, therefore, does not remain constant for the different fractions into which lubricating oil from any one source may be divided. The authors consider this fact to be an objection against its adoption.

Discussion of the Relative Indices

In reviewing the list of relative indices given above, it will be seen that they fall into two classes: those that assign a more or less constant figure to series of oil fractions from one base stock, viz., Viscosity Index, Pole Height, Independent V.I., Oil Type Constant, and Rational V.I., and those that do not, viz., Zero Viscosity Factor, Paraffin Proportion, Paraffin Relation, Normal Oil Relation, and Relative V.T.N. This corresponds with a division into methods that take into account the average "natural homology" of petroleum series and those that disregard this phenomenon.

In the authors' opinion there is no question but that, from a *practical* point of view, methods that take "natural homology" into account are to be preferred, and it is a great merit of Dean and Davis that this feature characterized the very simple unit which they evolved. It is obviously extremely valuable to the petroleum technologist, in quoting an index value of say +80, to realize that in the normal course of events approximately the same value will pertain to any fraction he can prepare by simple distillation (and dewaxing, if necessary) from the same base stock and that large fluctuations in this figure denote a change in chemical structure falling outside the "natural homology" normal in oil series.

There is, however, a further distinction to be made between methods of this type. They can be divided into the following categories:—

(1) methods that depend upon the existence of a very simple mathematical definition of a petroleum oil series, *i.e.*, Viscosity Pole Height, Oil Type Constant, and R.V.I.;

(2) methods that do not depend, in principle, on the nature of the mathematical definition of oil series, *i.e.*, Dean and Davis V.I. and the Independent V.I.

The methods in the first of these categories would fail if it became necessary to modify the reference series in such a way that they could no

longer be expressed in a simple mathematical form of the original type, whereas the methods in the second category could still be applied.

While the systems proposed by Dean and Davis and Malschaert comply with the requirements mentioned in category (2), they suffer from disadvantages which have already been enumerated. It is therefore necessary to develop a new system.

It would appear desirable at the present time to retain a system giving "round" figures such as 0 and 100 for the "steepest" and "flattest" oils usually encountered in commercial lubricants derived from petroleum by conventional refining methods.

In Part II of this paper the authors present a modification of the Dean and Davis V.I. which, it is shown, retains all the essential features of the scheme but entirely removes its anomalies.

PART II. PROPOSED MODIFICATION OF THE VISCOSITY INDEX SCHEME

It is concluded in Part I of this paper that a practical Viscosity Index scheme for lubricating oils should be based on the idea that oils can be considered as a family in which each member consists of a series of fractions of increasing viscosity with an average chemical composition changing in a regular manner as the viscosity increases. The fractions at all viscosity levels in a particular series may be considered, from a qualitative point of view, to show the same viscosity–temperature characteristics. The viscosity–temperature relationship of a given oil can then be characterized by identifying the oil by means of an index number as a member of a particular series of the family.

In the authors' opinion, the Viscosity Index scheme proposed by Dean and Davis comes nearest, among the existing schemes, to providing a satisfactory method of characterization. In the form in which it is at present used, however, this scheme shows certain irregularities and gives anomalous values for non-hydrocarbon oils which have exceptionally "flat" characteristics. In considering the possibility of modifying the scheme to cover a wider range of lubricants it is important to examine the basis on which oils are grouped in the scheme.

Definition of Series in the Family of Oils

If, from a number of crude oils of various origins, fractions of ascending molecular weight are prepared by careful fractional distillation (followed, if necessary, by removal of paraffin wax, but not by any drastic refining procedure) and if the viscosities of these fractions at one temperature, say 210° F, are plotted against the viscosities at a second temperature, such as 100° F, the result will be a fan of lines, which with few exceptions do not intersect. The fan composed by the majority would, in fact, resemble the portions of Figs 6 and 7 contained between the curves for the indices +100 and −100. This fact may be interpreted as meaning that the chemical constitution of the fractions in each series changes in a certain regular manner with increasing molecular weight, *i.e.*, that a certain "natural homology" exists in the lubricating oils prepared by

distillation from one base stock. The meaning of the word homology as here used is not the same as that employed for organic series, where it means the successive addition of a methylene group. Type analysis of the fractions shows that "homology," in its present meaning, is more complicated: the increment in average molecular structure varies both with molecular weight and with the position of the curve in the fan.

The curves in this fan may be regarded as constituting a natural family

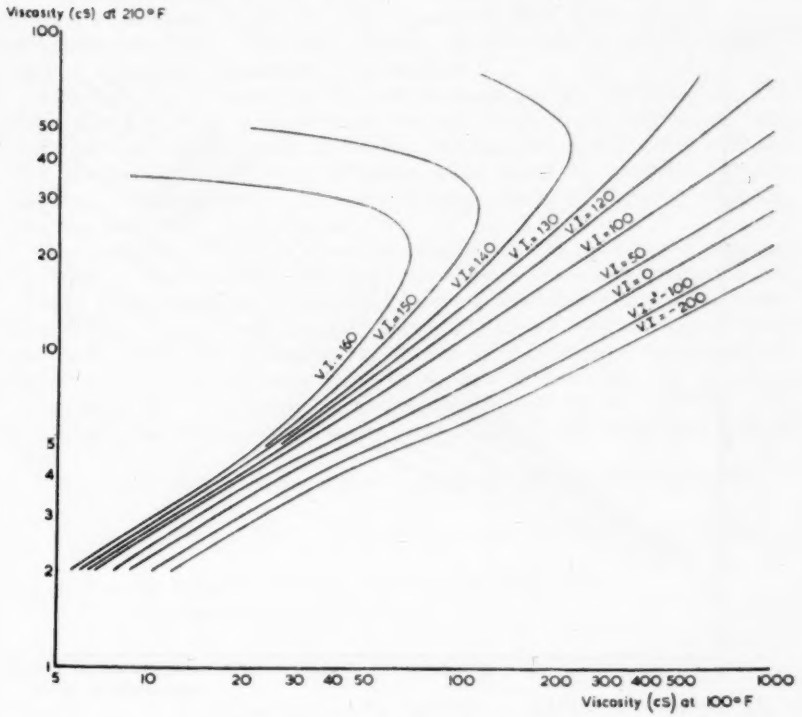

FIG 6

RELATION BETWEEN $V_{210°F}$ AND $V_{100°F}$ FOR OILS OF VARIOUS VALUES OF VISCOSITY INDEX

of lubricating oils having the same qualitative viscosity–temperature characteristics and they may form the basis of a scheme for defining the sensitivity of viscosity to change in temperature. If a series of fractions from a particular base stock does not behave in this standard manner, and such cases are known to occur, *i.e.*, if it gives a curve crossing the normal fan, it may evidently be regarded as showing an abnormal change in viscosity–temperature sensitivity with ascending molecular weight.

The basis for an index scheme described above is the one chosen by Dean and Davis, who selected, as their standards, a curve for a series of fractions having a relatively low temperature sensitivity (these were

prepared from a Pennsylvanian oil) and a curve for a series with a moderately high temperature sensitivity (prepared from a Gulf Coastal oil). The authors hold the view that there is no objection to this choice. Unfortunately, however, the method adopted by Dean and Davis for interpolating between these two standard curves leads to certain difficulties. These have already been mentioned in Part I, but one of them must be further elaborated here.

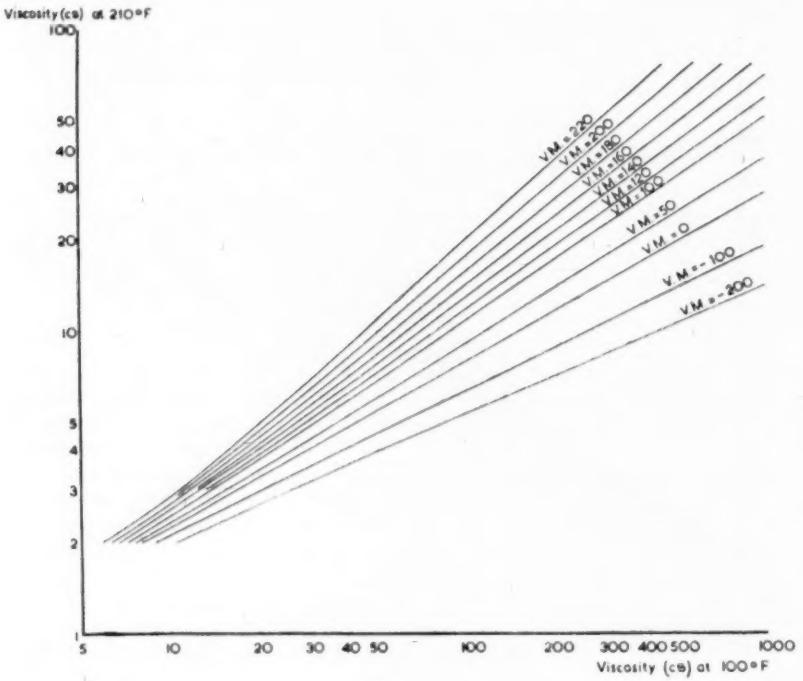

FIG 7

RELATION BETWEEN $V_{210°F}$ AND $V_{100°F}$ FOR OILS OF VARIOUS VALUES OF THE VISCOSITY MODULUS

If two curves from such a fan are chosen as standard oil series, it would seem reasonable to expect that mixtures prepared in a certain proportion from equiviscous fractions from the two standard series should follow the course of an intermediate curve. In other words, the index figure which is adopted should be an additive quantity, at all events for lubricants not differing too much in viscosity. The following example will show that this is not strictly realized in the Dean and Davis V.I. scheme.

Suppose that oils of 10 cs at 210° F in the *L* and *H* series of the V.I. scheme are mixed in equal proportions. At 100° F, the components of the mixture would have viscosities of 162·5 cs and 89·2 cs respectively,

according to the standard tables. On the assumption that the logarithms of viscosities are approximately additive, the viscosity of the mixture at 100° F would be 120·5 cs, giving a V.I. for the mixture of about 57. A similar calculation for a mixture of equal proportions of L and H oils of 40 cs viscosity at 210° F gives a V.I. of about 63. Thus, the V.I. of a series of oils, composed of L and H components in equal proportions is not equal to 50 and is not independent of viscosity level.

It follows, more generally, that mixtures in constant proportions of oils of the same viscosity at 210° F from two or more oil series, as defined by their V.I. numbers, would also give a series of oils in which the V.I. varied with viscosity level. The V.I. of such a series would, in fact, be constant only if viscosities themselves were additive.

Although, as indicated by the above example, the variations in V.I. with viscosity level in these cases are not likely to be very great, they constitute an inconsistency of the V.I. scheme and demonstrate that the V.I. gives an unsatisfactory definition of oil series intermediate between the two reference series. A more suitable means of defining oil series may be devised in the following way.

Consider a modified index scheme, similar to the present V.I. scheme, in which the two reference series of hydrocarbon oils are designated as the L' and H' series respectively, which may be modifications of the present L and H series. It will then be supposed that, as a logical requirement, the index numbers corresponding to binary mixtures of constant proportions of oils of the same viscosity at 210° F from the two reference series must be independent of the viscosity level of the mixture. Let the binary mixtures contain p per cent of the H' oil component in each case.

Then, the viscosity of the binary mixture at 100° F will be given by :—

$$p \times f(H') + (100 - p) \times f(L') = 100 \times f(U) \quad . \quad \text{(XXXVIII)}$$

where f = the function of viscosity which is additive;
U = the viscosity of the mixture.

On re-arranging the above equation, we get

$$p = 100 \,.\, [f(L') - f(U)]/[f(L') - f(H')] \quad . \quad \text{(XXXIX)}$$

If, now the right-hand side of equation (XXXIX) is taken to give the index number in the modified scheme, all mixtures containing the same proportions of oils of the L' and H' series will have the same index number, which, in fact, will be numerically equal to the percentage of H' oil in the mixture. Similarly, mixtures of constant proportions of oils at the same viscosity at 210° F from two series of oils having different index numbers will constitute another series of oils of constant index number.

Thus, the form of the index number in the present V.I. scheme may be retained, but inconsistencies of the kind discussed above will be eliminated if the function of viscosity which is additive is inserted in equation (XVII) in place of the viscosity itself.

It should be emphasized that the self-consistency of this modified

scheme over the range of index numbers from 0 to 100 will be independent of :—

(1) the particular form of the function of viscosity which proves to be additive;

(2) the particular form of the relationship between the viscosities at 210° F and 100° F for the oils selected as the L' and H' reference series.

Definition of Viscosity Modulus

At the present time, there is no known theoretical function of viscosity which is strictly additive. A number of empirical functions are, however, approximately additive, and of these, the logarithm of viscosity, which gives reasonably reliable figures for components not differing too much in viscosity, is the simplest and most suitable for the present purpose. If the logarithm of viscosity is taken as the appropriate function in equation (XXXIX), therefore, an index number will be obtained which will be very largely free from the inconsistencies discussed above. It is proposed to describe the index number calculated in this way as the "*Viscosity Modulus*," (V.M.) which may be written

$$100 \,.\, (\log L' - \log U)/(\log L' - \log H') \,. \quad . \quad . \quad \text{(XL)}$$

A second advantage of the Viscosity Modulus, calculated on the basis of the logarithms of viscosities, lies in the fact that it is equivalent to a relative index using the average value of either of the functions $1/v \,.\, dv/dT$ or $d \log v/d(1/T)$ as the measure of viscosity–temperature characteristics. Thus, the average value of $1/v \,.\, dv/dT$, which Ramser has termed the Viscosity–Temperature Rating (VTR), is given by :—

$$\text{VTR} = A \,(\log v_2 - \log v_1) \quad . \quad . \quad . \quad \text{(XLI)}$$

where A = a constant for a given temperature range and independent of the type of oil;

v_1 = viscosity at 100° F;

v_2 = viscosity at 210° F.

The Whalley and Leach function gives an average value of a similar form (compare equations (XV) and (XVI)).

By introducing the value of the viscosity of the given oil at 210° F, equation (XL) may be written as follows :—

$$\frac{\text{V.M.}}{100} = \frac{(\log v_2 - \log L') - (\log v_2 - \log U')}{(\log v_2 - \log L') - (\log v_2 - \log H')} \,. \quad . \quad \text{(XLII)}$$

The quantities in each of the brackets in equation (XLII) are proportional to the corresponding values of the Viscosity–Temperature Ratings for the oils concerned. On substituting for these values, according to equation (XLI), and re-arranging, the Viscosity Modulus may be expressed as follows :

$$\text{V.M.} = 100 \,\frac{(\text{V.T.R.}_{(L')} - \text{V.T.R.}_{(U)})}{(\text{V.T.R.}_{(L')} - \text{V.T.R.}_{(H')})} \,. \quad . \quad \text{(XLIII)}$$

(This expression also holds if V.T.R. is replaced by the average value of the Whalley and Leach function.)

The V.M. may, therefore, be regarded as giving the relation between the Viscosity–Temperature Rating (or average value of $d \log v/d(1/T)$ for the given oil and the same function for the corresponding members in the L' and H' reference series, having the same viscosity at 210° F.

In considering the arguments given above it might be remarked that the Walther function, log log $(v + a)$, also shows a considerable measure of additivity and that the Independent Viscosity Index previously proposed by Malschaert [22] with another object in view (as discussed in Part I) should hence be as satisfactory as the Viscosity Modulus from the aspect of additivity of the resultant index figure. Whilst this is true, the authors must emphasize that the Walther function does not bear the simple relationship to the functions $1/v \,.\, dv/dT$ and $d \log v/d(1/T)$ demonstrated above. The authors consider this objection to be of sufficient importance for rejecting the I.V.I. in favour of the Viscosity Modulus.

Interpretation of Index Numbers Greater than 100 and Less than 0

An element of artificiality is inevitably introduced in attempting to extend an index scheme, of the type being discussed, outside the limits of the reference series of oils. This applies particularly to index numbers appreciably greater than 100, since the liquids concerned will usually no longer be simple hydrocarbon oils but either non-hydrocarbon oils or solutions of polymers in hydrocarbon oils, and there is no obvious reason why series of such oils and solutions should fit into a system based on simple hydrocarbon lubricating oils. When the Viscosity Modulus is adopted in place of the Viscosity Index the difficulty also arises of interpreting index numbers outside the range 0 to 100, since the Viscosity Modulus of a given oil is approximately numerically equal to the percentage of an oil of the H' series in a mixture of L' and H' oils which has the same viscosity–temperature characteristics as the given oil. A logical extension of the scheme to " flatter " and " steeper " oils than those of the reference series is, however, possible on the following lines.

It is supposed that the oils of the L' and H' reference series may themselves be regarded as equivalent to mixtures of constant proportions of two hypothetical oil series of extreme " steepness " and flatness," which may be designated the " α " and " ω " series respectively.

The viscosity modulus, X_U, of a given oil relative to the α and ω reference series, instead of the L' and H' series, would then be given by :

$$X_U = 100 \,.\, (\log \alpha - \log U)/(\log \alpha - \log \omega) \quad . \quad \text{(XLIV)}$$

Similarly, the moduli of the corresponding oils of the L' and H' series, relative to the α and ω series, may be written as $X_{H'}$ and $X_{L'}$ respectively and expressed in the above form. Then, it can be shown that

$$100 \,.\, (\log L' - \log U)/(\log L' - \log H') = 100\,(X_U - X_{L'})/(X_{H'} - X_{L'}) \,. \quad . \quad \text{(XLV)}$$

The left-hand side of equation (XLV) has the form of the Viscosity Modulus of the given oil relative to the L' and H' series. Writing this modulus as V.M., we have :—

$$\text{V.M.} = 100 \,.\, (X_U - X_{L'})/(X_{H'} - X_{L'}) \quad . \quad \text{(XLVI)}$$

Since $X_{H'}$ and $X_{L'}$ in equation (XLVI) will be constant for the index system, the Viscosity Modulus of the given oil calculated with reference to the L' and H' series will be related linearly to the modulus X_U calculated with reference to the hypothetical α and ω reference series. The value of the Viscosity Modulus will obviously lie between 0 and 100 when the value of X_U lies between the values $X_{L'}$ and $X_{H'}$. The value of V.M. will be negative when X_U is less than $X_{L'}$ *i.e.*, the given oil is "steeper" than oils of the L' series. The value of V.M. will be greater than 100 when X_U is greater than $X_{H'}$, *i.e.*, the given oil is "flatter" than oils of the H' series.

Anomalous Index Numbers

It is well known that, for values of the V.I. considerably above 100, there are two positive values of the viscosity at 210° F which give the same V.I. for a single value of the viscosity at 100° F. The possibility of anomalies of this kind occurring in an index scheme of the type being discussed depends both on the way in which oil series are defined and on the particular form of the relationship between the viscosities at 100° and 210° F for the oils of the two reference series. The Viscosity Index and the Viscosity Modulus will be compared in this respect.

(1) *Viscosity Index*

The present Viscosity Index tables for viscosities at 210° F above 7·3 cs (50 S.U.S.) are based on the original L and H series of Dean and Davis, as defined by equations (XVIII) and (XIX) in Part I of this paper. By combining these equations with equation (XVII) defining Viscosity Index, the relationship between the viscosities at 100° and 210° F for a series of oils having any given index number in the scheme may be obtained, as follows:—

$$y = (0{\cdot}216 - 0{\cdot}175\ \text{V.I.}/100)x^2 + (12{\cdot}07 + 0{\cdot}498\ \text{V.I.}/100)x - 721{\cdot}2 + 246\ \text{V.I.}/100 \quad . \quad \text{(XLVII)}$$

where y = viscosity at 100° F, S.U.S.;
x = " " 210° F " ;
V.I. = Viscosity Index.

For values of V.I. considerably above 100, the curves corresponding to equation (XLVII) show two positive values of x for each value of y, *i.e.*, the value of y passes through a maximum as x increases. This may be shown as follows. By differentiating equation (XLVII) and equating the result to zero, the relationship between the value of x at the maximum value of y for different values of V.I. is obtained:—

$$\text{V.I.} = 100\,.\,(0{\cdot}432\,X + 12{\cdot}07)/(0{\cdot}35\,X - 0{\cdot}5) \quad . \quad \text{(XLVIII)}$$

where X = value of viscosity at 210° F corresponding to maximum value of viscosity at 100° F.

From equation (XLVIII) it may be shown that, as the value of X increases, the value of the corresponding V.I. decreases and reaches a limiting value of $0{\cdot}432/0{\cdot}35 \times 100 = 123{\cdot}5$ for very high values of X. It follows that anomalies in the Dean and Davis scheme theoretically begin at index numbers above about 123·5, when two values of x, one very large, will

correspond to a single value of y. As the V.I. increases above 123·5 the value of X rapidly decreases and for index numbers above about 140 the two values of x corresponding to a certain value of y will fall within the range of viscosities at 210° F which are of practical interest.

The anomalies of the V.I. system are shown graphically in Fig 6, which is based on the data for the L and H series given in the present V.I. tables.

(2) *Viscosity Modulus*

As has been stated previously, the additive character of V.M. values is independent of the basic viscosity series which are employed and hence these series may be chosen as desired.

The series forming the basis of the present V.I. might be adopted for this purpose and it is possible to show by mathematical analysis in a manner similar to that followed in the preceding section, that no anomalies would occur in this case in the range of V.M. values and viscosities encountered in practice.

The authors, however, are not in favour of the series at present used for the V.I., on account of the irregularities (already discussed in Part I) resulting from the joining up of several interpolation formulæ. They prefer to use series giving a smooth relationship and suggest the adoption of the first series of kinematic units published, viz., those of Hersh, Fisher, and Fenske (cf. Part I, equations (XX) and (XXI)). As stated previously, these series have proved to be a satisfactory basis for calculation of the ordinary V.I. and in the authors' opinion they approximate more closely to the course of natural oil series in the fan previously referred to (cf. definition of series in the family of oils) than those now in use.

The occurrence of a maximum in the curve for a particular value of V.M. on the graph connecting the viscosities at 210° and 100° F can be predicted as follows.

By re-arranging expression (XL) we get :—

$$\log U = \log L' \,(100 - \text{V.M.})/100 + \log H' \,.\, \text{V.M.}/100 \quad . \quad \text{(XLIX)}$$

By differentiating this with respect to x (the viscosity at 210° F) and equating dU/dx to zero for the maximum

$$(\text{V.M.}_{\max} - 100)/\text{V.M.}_{\max} = L'/H' \,.\, (dH'/dx)/(dL'/dx) \quad . \quad \text{(L)}$$

is obtained and can be applied to any basic series of viscosities. If equation (L) is used to test Hersh, Fisher, and Fenske's series (equations (XX) and (XXI), H' and L' standing for v_{100} and x for v_{210}) the result is

$$\frac{\text{V.M.}_{\max} - 100}{\text{V.M.}_{\max}} = 0{\cdot}833 \times \frac{(x - 0{\cdot}213x^{-1{\cdot}08})(1 + 0{\cdot}665x^{2{\cdot}33})}{(x - 0{\cdot}500x^{-1{\cdot}33})(1 + 0{\cdot}230x^{2{\cdot}08})} \quad . \quad \text{(LI)}$$

The right-hand side of this equation has, for large values of x, a limiting value of 0·833, making $\text{V.M.}_{\max} = 600$. This figure becomes 645 when $x = 5$ cs and 1750 when $x = 2$ cs, *so that, for viscosity moduli within the range of practical interest, no anomalous V.M. figures will be encountered.* This is shown graphically in Fig 7.

By way of an illustration it may be noted that the anomaly shown in Table I for the ester and silicone does not arise in the V.M. scheme. Thus

whereas both the liquids showed a V.I. of about 150, the viscosity moduli are 206 and 308 respectively.

If, in the future, as a result of experimental investigation, it became

TABLE VI

Table for Calculation of Viscosity Modulus

V.M. = 100 . $(X - \log_{10} U)/Y$, where U = viscosity in cs of oil under examination at 100° F.

V_{210}, cs	X	Y	V_{210}, cs	X	Y
2·00	0·8906	0·0589	4·25	1·5121	0·1324
2·05	0·9120	0·0602	4·30	1·5214	0·1338
2·10	0·9327	0·0616	4·35	1·5306	0·1351
2·15	0·9529	0·0630	4·40	1·5397	0·1364
2·20	0·9726	0·0646	4·45	1·5487	0·1378
2·25	0·9917	0·0662	4·50	1·5576	0·1392
2·30	1·0103	0·0678	4·55	1·5665	0·1406
2·35	1·0284	0·0695	4·60	1·5752	0·1420
2·40	1·0461	0·0712	4·65	1·5838	0·1434
2·45	1·0634	0·0729	4·70	1·5923	0·1447
2·50	1·0803	0·0747	4·75	1·6008	0·1460
2·55	1·0968	0·0765	4·80	1·6091	0·1473
2·60	1·1129	0·0784	4·85	1·6173	0·1485
2·65	1·1288	0·0803	4·90	1·6254	0·1497
2·70	1·1443	0·0821	4·95	1·6335	0·1511
2·75	1·1596	0·0839	5·0	1·6416	0·1525
2·80	1·1744	0·0856	5·1	1·6572	0·1548
2·85	1·1890	0·0874	5·2	1·6726	0·1572
2·90	1·2033	0·0891	5·3	1·6877	0·1595
2·95	1·2174	0·0909	5·4	1·7025	0·1619
3·00	1·2310	0·0926	5·5	1·7170	0·1642
3·05	1·2445	0·0943	5·6	1·7313	0·1665
3·10	1·2577	0·0960	5·7	1·7452	0·1686
3·15	1·2707	0·0976	5·8	1·7590	0·1708
3·20	1·2833	0·0992	5·9	1·7725	0·1730
3·25	1·2959	0·1009	6·0	1·7858	0·1751
3·30	1·3084	0·1026	6·1	1·7989	0·1773
3·35	1·3207	0·1043	6·2	1·8117	0·1793
3·40	1·3326	0·1060	6·3	1·8244	0·1814
3·45	1·3444	0·1077	6·4	1·8368	0·1834
3·50	1·3560	0·1093	6·5	1·8491	0·1855
3·55	1·3676	0·1110	6·6	1·8611	0·1874
3·60	1·3789	0·1127	6·7	1·8730	0·1894
3·65	1·3900	0·1144	6·8	1·8846	0·1912
3·70	1·4009	0·1160	6·9	1·8961	0·1931
3·75	1·4117	0·1175	7·0	1·9074	0·1948
3·80	1·4224	0·1190	7·1	1·9186	0·1967
3·85	1·4330	0·1205	7·2	1·9297	0·1986
3·90	1·4433	0·1220	7·3	1·9405	0·2003
3·95	1·4535	0·1235	7·4	1·9512	0·2021
4·00	1·4635	0·1250	7·5	1·9618	0·2038
4·05	1·4735	0·1265	7·6	1·9722	0·2055
4·10	1·4833	0·1280	7·7	1·9825	0·2072
4·15	1·4930	0·1295	7·8	1·9926	0·2088
4·20	1·5026	0·1310	7·9	2·0026	0·2104

TABLE VI—(*continued*)

V_{210}, cs	X	Y	V_{210}, cs	X	Y
8·0	2·0125	0·2121	17·5	2·6263	0·3135
8·1	2·0223	0·2137	18·0	2·6483	0·3173
8·2	2·0319	0·2152	18·5	2·6698	0·3209
8·3	2·0414	0·2167	19·0	2·6906	0·3244
8·4	2·0509	0·2183	19·5	2·7109	0·3278
8·5	2·0602	0·2199	20·0	2·7306	0·3311
8·6	2·0694	0·2215	20·5	2·7500	0·3343
8·7	2·0784	0·2229	21·0	2·7688	0·3374
8·8	2·0874	0·2245	21·5	2·7873	0·3405
8·9	2·0963	0·2258	22·0	2·8052	0·3434
9·0	2·1051	0·2273	22·5	2·8226	0·3464
9·1	2·1137	0·2286	23·0	2·8399	0·3492
9·2	2·1224	0·2301	23·5	2·8567	0·3520
9·3	2·1308	0·2315	24·0	2·8732	0·3547
9·4	2·1392	0·2329	24·5	2·8895	0·3574
9·5	2·1475	0·2342	25·0	2·9052	0·3600
9·6	2·1557	0·2356	25·5	2·9207	0·3626
9·7	2·1639	0·2369	26·0	2·9358	0·3651
9·8	2·1719	0·2383	26·5	2·9507	0·3676
9·9	2·1799	0·2396	27·0	2·9653	0·3701
10·0	2·1878	0·2409	27·5	2·9797	0·3725
10·2	2·2031	0·2431	28·0	2·9938	0·3749
10·4	2·2183	0·2456	28·5	3·0077	0·3772
10·6	2·2333	0·2481	29·0	3·0212	0·3794
10·8	2·2479	0·2505	29·5	3·0346	0·3816
11·0	2·2622	0·2528	30	3·0477	0·3838
11·2	2·2765	0·2554	31	3·0734	0·3882
11·4	2·2909	0·2581	32	3·0982	0·3922
11·6	2·3047	0·2605	33	3·1225	0·3963
11·8	2·3179	0·2629	34	3·1458	0·4002
12·0	2·3310	0·2650	35	3·1685	0·4040
12·2	2·3440	0·2671	36	3·1905	0·4077
12·4	2·3568	0·2693	37	3·2119	0·4112
12·6	2·3692	0·2713	38	3·2328	0·4147
12·8	2·3815	0·2733	39	3·2531	0·4181
13·0	2·3937	0·2754	40	3·2729	0·4214
13·2	2·4057	0·2773	41	3·2922	0·4246
13·4	2·4173	0·2793	42	3·3110	0·4277
13·6	2·4289	0·2812	43	3·3294	0·4308
13·8	2·4404	0·2830	44	3·3474	0·4338
14·0	2·4517	0·2847	45	3·3649	0·4367
14·2	2·4627	0·2864	46	3·3821	0·4395
14·4	2·4736	0·2881	47	3·3990	0·4424
14·6	2·4844	0·2899	48	3·4154	0·4451
14·8	2·4951	0·2918	49	3·4315	0·4478
15·0	2·5056	0·2937	50	3·4473	0·4504
15·5	2·5313	0·2979	51	3·4628	0·4530
16·0	2·5561	0·3020	52	3·4780	0·4556
16·5	2·5801	0·3059	53	3·4929	0·4581
17·0	2·6035	0·3097	54	3·5075	0·4605

TABLE VI—(*continued*)

$V_{210°,\ cs}$	X	Y	$V_{210°,\ cs}$	X	Y
55	3·5218	0·4629	65	3·6524	0·4846
56	3·5359	0·4652	66	3·6644	0·4866
57	3·5498	0·4675	67	3·6761	0·4886
58	3·5634	0·4698	68	3·6877	0·4905
59	3·5767	0·4720	69	3·6991	0·4924
60	3·5899	0·4742	70	3·7104	0·4943
61	3·6028	0·4764	71	3·7214	0·4962
62	3·6155	0·4785	72	3·7324	0·4980
63	3·6280	0·4806	73	3·7432	0·4998
64	3·6403	0·4826	74	3·7538	0·5015
			75	3·7643	0·5033

advisable to revise the data for the L' and H' reference series, it is improbable that any modification would be sufficient to cause the occurrence of anomalous values within the range of viscosities at present covered by the V.M. scheme. Any extension to viscosities below 2 cs at 210° F would, however, need to be examined in this respect.

CALCULATION OF THE VISCOSITY MODULUS

Table VI gives the values of $\log L'$ (referred to as X) and of $\log L' - \log H'$ (referred to as Y) and the V.M. may hence be calculated by the formula

$$\text{V.M.} = 100 \,.\, (X - \log_{10} U)/Y \quad . \quad . \quad . \quad \text{(LII)}$$

where U is the viscosity at 100° F of the oil under examination. Except for looking up one logarithm, the calculation is hence entirely similar to that of the present V.I.

A somewhat more detailed table may be desirable for general use.

EXTENSION TO TEMPERATURE RANGES OTHER THAN 100° TO 210° F

The viscosity modulus applying to any other temperature interval $(t_1 - t_2)$ may in principle be obtained by the method described in Part I. In this method the straight line passing through the points obtained by plotting the viscosities at t_1 and t_2 on a chart similar to that of the ASTM is extrapolated to give the apparent values of the viscosities at 100° and 210° F, as indicated in Fig 1. In actual practice it will be found that the values of $v_{210°\,F}$ and $v_{100°\,F}$ obtained graphically are only suitable for a very rough estimate, owing to the errors introduced by extrapolating over a long range. For reliable results, extrapolation must be done by calculation, using the Walther formula. The figures obtained will depend on the value of a adopted in this formula, especially with oils of low viscosity.

The following example will illustrate the procedure. The viscosity data for two commercial lubricants of the polyethylene glycol type, as given in the manufacturer's booklet, together with the figures for V.I. and V.M. calculated directly from $v_{210°\,F}$ and $v_{100°\,F}$, are set out in Table VII(a).

TABLE VII(a)

Lubricant	Observed viscosities, cs					V.I.	$(V.M.)_{100^\circ F}^{210^\circ F}$
	210° F	100° F	0° F	−20° F	−40° F		
A	6·80	36·5	1740	7,200	50,000	143½	168½
B	18·8	119	8800	47,000	—	140½	188

When plotted on the ASTM chart, these viscosities give lines showing a marked curvature. Mathematical extrapolation, using the Walther formula with $a = 0{\cdot}7$ (see footnote on page 197) yields the apparent viscosities at 210° and 100° F and corresponding values for the V.M. given in Table VII(b).

TABLE VII(b)

Lubricant	Apparent viscosities at		$(V.M.)_{t_2}^{t_1}$
	210° F	100° F	
A, from $v_{0^\circ F}$ and $v_{-40^\circ F}$ . .	4·29	27·55	$(V.M.)_{-40^\circ F}^{0^\circ F} = 59\frac{1}{2}$
A, from $v_{100^\circ F}$ and $v_{0^\circ F}$ . .	5·78	(36·5)	$(V.M.)_{0^\circ F}^{100^\circ F} = 113\frac{1}{2}$
B, from $v_{100^\circ F}$ and $v_{-20^\circ F}$ . .	13·04	(119)	$(V.M.)_{-20^\circ F}^{100^\circ F} = 116$

These results demonstrate the value of determining an index figure over several temperature ranges. Thus lubricant A, which gives an index figure of far more than 100 by the conventional calculation from the viscosities at 210° and 100° F, has a considerably steeper slope than a Pennsylvanian oil of equivalent viscosity over the range 0° to −40° F.

SENSITIVITY OF THE V.M.

Objection is sometimes taken to what is considered to be an excessive sensitivity of the viscosity index to small deviations in viscosity. The sensitivity of the V.M. is of the same order as that of the V.I. In the opinion of the authors it is not excessive and fluctuations in the figure found are due more to lack of precision in the determination of viscosity than to any deficiencies in the index system. In practice it must be recognized that the estimation of the V.M. is subject to considerable experimental error, and due allowance should be made for this when using it.

The following example shows that the V.M. does not unduly exaggerate the actual differences between oils and that its sensitivity does not exceed the purpose for which it is intended.

Consider three oils, each having a viscosity of 5·00 cs at 210° F, for which the viscosity moduli are 100, 99, and 95. The viscosities at 0° F, calculated by the Walther formula using $a = 0{\cdot}7$, would be 1530, 1555, and 1647 cs respectively. Thus, the viscosity at 0° F of the oil with

V.M. = 99 is about 1·6 per cent higher and that of the oil with V.M. = 95 about 7·7 per cent higher than the corresponding viscosity with the oil of V.M. = 100.

Comparison between V.I. and V.M.

Table VIII gives a comparison between the values of the present Viscosity Index and the Viscosity Modulus for oils of a number of viscosities and values of the V.I.

If the same reference series had been employed for calculation of the V.M. and the V.I., the value of the V.M. at 0 and +100 V.I. would also have been exactly 0 and +100. The considerable differences occurring in this correlation at lower viscosities are due to discrepancies in the reference series and particularly to the "waves" in the present V.I. series.

It will be seen that, except for variations caused by the above-mentioned factor, a V.I. of −100 is equivalent to a V.M. of about −60, a V.I. of +50 to a V.M. of about +30 to +40, whilst above +100 the values of the V.M. are larger than those of the V.I. In other words, the excessive

Table VIII

ν_{210} cs	Viscosity Modulus				
	V.I. = −100	V.I. = 0	V.I. = +50	V.I. = +100	V.I. = +120
2	−194	−54	+27	+118	+158
3	− 75	+19	+75	+138	+166
5	− 65	+ 8	+54	+107	+132
10	− 77	−10	+37	+ 99	+131
20	− 61	− 3	+39	+101	+138
40	− 56	− 5	+35	+100	+144
60	− 55	− 8	+31	+ 97	+148
75	− 55	− 9	+28	+ 96	+151

sensitivity of the V.I. scale at its lower end has been diminished and its lack of sensitivity at the upper end remedied.

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Note Added to Proof.

The Additive Function of Viscosity

Suppose that it is possible to find some function of viscosity, viz., $F(v)$, that is additive for oils in binary mixtures at any given temperature. The additivity relationship may be defined as follows :—

$$F(v_{12}) = pF(v_1) + (100 - p)F(v_2) \quad . \quad . \quad . \quad (1)$$

where v_1 = viscosity of oil (1) at temperature T;
v_2 = viscosity of oil (2) at temperature T;
v_{12} = viscosity of oil mixture at temperature T;
p = % of oil (1) in mixture.

Differentiating equation (1) with respect to (T) we get :—

$$\frac{dF(v_{12})}{dv_{12}} \cdot \frac{dv_{12}}{dT} = \frac{pdF(v_1)}{dv_1} \cdot \frac{dv_1}{dT} + (100 - p)\frac{dF(v_2)}{dv_2} \cdot \frac{dv_2}{dT} \quad . \quad (2)$$

At the equiviscous temperature (Te), we may assume that

$$(v_1)_{Te} = (v_2)_{Te} = (v_{12})_{Te}$$

The differential coefficients of the additive function of viscosity in equation (2) will also be equal at the equiviscous temperature, and may be eliminated from equation (2), giving :—

$$\left(\frac{dv_{12}}{dT}\right)_{Te} = p\left(\frac{dv_1}{dT}\right)_{Te} = (100 - p)\left(\frac{dv_2}{dT}\right)_{Te} \quad . \quad . \quad (3)$$

Thus, provided it can be assumed that an additive function of viscosity exists, it is concluded that the values of $\frac{dv}{dT}$ for oils at the equiviscous temperature are additive in binary mixtures. This implies that, in any scheme of classifying oils according to their temperature susceptibilities,

the indices associated with oils of the same viscosity level should also be additive.

Suppose, now, that it is possible to find some function of viscosity, $F^1(v)$, that is linearly related to some function of temperature, viz., $f(T)$. We may then write:

$$\frac{dF^1(v)}{df(T)} = m$$

where (m) is a constant for a given oil at all temperatures. It can readily be shown from equation (3) that the values of (m) for oils in binary mixtures will also be additive, *i.e.*,

$$m_{12} = pm_1 + (100 - p)m_2 \quad . \quad . \quad . \quad (4)$$

The value of (m) may also be written as follows:—

$$m = \frac{F^1(v)_T - F^1(v)_{Te}}{f(T) - f(Te)} \quad . \quad . \quad . \quad . \quad (5)$$

where Te = equiviscous temperature;
T = any other temperature.

On substituting appropriate values of (m) from equation (5), equation (4) reduces to:—

$$F^1(v_{12})_T = pF^1(v_1)_T + (100 - p)F^1(v_2)_T \quad . \quad . \quad (6)$$

Equation (6) shows that $F^1(v)$ is an additive function of viscosity for binary mixtures at any given temperature and $F^1(v)$ may therefore be identified with $F(v)$ in equation (1).

It follows that a classification scheme based on the additivity of the viscosity at some standard temperature, *e.g.*, 100° F, in binary mixtures of oils of the same viscosity level but different temperature susceptibilities is equivalent to a scheme based on the fundamental relationship for the additivity of the values of $\frac{dv}{dT}$ for these oils in binary mixtures at the equiviscous temperature.

In the V.M. scheme the logarithm of the viscosity at 100° F has been suggested as an approximate and convenient additive function of viscosity which may be used as the basis of the scheme.

Discussion

The Chairman: We have listened first to an extremely interesting review of the present situation in regard to viscosity–temperature relationships and their peculiarities, and secondly, to some very interesting suggestions on what we should do about it.

Dr A. H. Nissan: The first words I want to say are words of congratulations and thanks for the authors' really well-done job as shown in Part I of their paper. When one looks dispassionately at the indices, numbers, factors, and moduli that have been put forth in the past to characterize the viscosity–temperature relationship of oils, one is, in the words of the song,

" bewitched, bothered, and bewildered." Yet the authors managed to get order out of chaos and to group and classify the various characteristics, giving us in the process an extremely informative summary of the chief attributes of each proposal as well as a judicious and fair criticism of its shortcomings. They have, therefore, served the industry well by compiling all available information together and thus enabling us all to have a panoramic view which, at the same time, does not lack in perspective. For this they deserve the industry's thanks. The conclusion they have drawn is that none of the systems proposed is wholly satisfactory. I doubt if there are many people who would quarrel with this conclusion. I certainly do not.

Where I part company with the authors is in Part II, where they introduce yet another modulus. I think that they have missed the main lesson of their own excellent study of Part I. This, in my view, is the following: the viscosity–temperature relationship of oils is a function of more than one variable. It is, therefore, mathematically impossible to describe it with one figure. Six years ago Hardiman and I suggested that the best we could do was to admit the arbitrary, unsatisfactory nature of any single-point solution and merely to try to rationalize what was available. I still hold the same opinion, even after having had the benefit of studying the authors' modulus since its inception two or three years ago and despite the very frank and full discussions we have had together during this time, for which I make now public acknowledgment with thanks. I think—and I hope the authors will forgive me repeating in public what they know is my opinion from private discussions—that the modulus they are proposing is entirely unnecessary because it has nothing of serious importance to offer which is not possessed to an equal degree by other systems already available, and furthermore, because it has, unfortunately, the major disturbing factor that it does not correlate well with systems already accepted. Indeed, I fear that the authors, after a praiseworthy and fairly successful attempt to bring order out of chaos in Part I, have more or less undone their good work by adding yet another modulus which suffers from most of the criticisms found so justifiable against the others. I will, therefore, detail my reasons for not welcoming the modulus as a solution to this perennial problem. Before I do so I think I should make clear what I understand by " fundamental," because the authors do, on occasion, use it in connexion with some functions of viscosity.

The word " fundamental " is used in quotation marks here in order to emphasize the dangers which sometimes attend its use. I want to stress that not only the logarithm of a property is not necessarily more " fundamental " than the property itself but even such a pleasingly academic-looking expression as $1/v \,.\, dv/d(1/T)$ need not *necessarily* be more " fundamental " than say $(v_2 - v_1)/(T_2 - T_1)$, which looks very " practical." The reason why $[1/v \,.\, dv/d(1/T)]$ or its equivalent $[d \log v/d(1/T)]$ is used in viscosity studies is that for certain so-called " simple liquids " a plot of $\log v$ *vs* $1/T$ yields a straight line over a certain range in temperature. From this empirical fact several theoretical deductions were obtained by workers on the physical chemistry aspect of viscosity. Once the plot of $\log v$ *vs* $1/T$ gives a markedly curved line $d \log v/d(1/T)$ loses its simplicity and a great deal—though not all—of the physico-chemical interpretation

based on the straight-line plots. Thus any one value for $d \log v/d(1/T)$ obtained from the infinite values possible for a curve with a varying radius or curvature becomes no more fundamental than, say, $(v_2 - v_1)/(T_2 - T_1)$ for the purpose of comparisons unless all sorts of assumptions are made as to the exact significance and interpretation of such functions. The essential point here is that viscous oils in the range of 2 to 75 cs at 210° F do *not* yield straight lines when a plot of log v *vs* $(1/T)$ is made. Otherwise the ASTM chart would have not been necessary. Appeal to the "fundamental" nature of functions involving (log v) instead of v—such as Ramser's function n, or the V.M., etc., etc.,—is an appeal to the emotive faculties, and cannot therefore be the basis of a technical discussion of the suitability or otherwise of these functions to characterize the viscosity–temperature sensitivity of oils in industrial and commercial specifications.

With this background let me discuss the physico-chemical significance of the V.M. The authors make three claims as the bases for the desirability of the V.M.: (1) that it is an additive property of oils, (2) that it is related to Ramser's function which is taken to be as "fundamental," and (3) that it is an expression for a peculiar "natural homology." I believe that the V.M. fails to pass the test on these three assumptions chosen by the authors as their main supports for the V.M. structure.

(1) *The V.M. is not Additive.* The authors state, "A number of empirical functions are, however, approximately additive and of these, the logarithm of viscosity, which gives reasonably reliable figures *for components not differing too much in viscosity*, is the simplest and most suitable for the present purpose." (The italics are mine.) This statement is true for "components not differing too much in viscosity." The mistake is to assume that oils of, say, 0 to 100 V.I. *even with the same viscosity at* 210° *F* will have viscosities at 100° F "not differing too much." Table I gives some comparisons of viscosities at 100° F for oils with the same viscosity at 210° F; the differences in viscosity at 100° F would be even larger than those shown if the difference in V.I. were bigger than 100 units or if the oils did not possess the same viscosity at 210° F.

TABLE I

Viscosity at 210° F	Viscosity at 100° F	
	V.I. = 0	V.I. = 100
75	6446·7	1921·3
50	2990·8 (A)	1010·4
25	826·5	349·3 (B)
10	162·5	89·2

The additivity of the logarithm of viscosity is of the same order of accuracy as the additivity of the logarithm of vapour pressure; this means that it is sometimes "reasonable" but generally not. It is essential to the argument (that the V.M. is additive) to show that the V.M. of any mixture of oils, no matter what viscosities they possess at 100° and 210° F (provided the latter are between 2 and 75 cs) is an additive property. Until this is established as fact we must abide by the general observation that the

logarithm of viscosities is not, in general, additive. To avoid extremes and quote an example with medium properties: would the authors claim that the V.M. would be additive for the middle oils shown in the table, say, for oil A of 0 V.I. and 50 cs at 210° F mixed with oil B of 100 V.I. and 25 cs at 210° F.

Despite all this let us grant that the V.M., under limited conditions, is approximately additive, but so are Walther's function and Malschaert's I.V.I. Why, then, not adopt either of these earlier functions if additivity, even to a slight extent, is so very important? Apparently because the V.M. is related to the V.T.R., whilst Walther's and Malschaert's functions cannot claim such an aristocratic lineage.

(2) *The V.M. is only fortuitously related to the Ramser function.* Here what is essential to the argument is that the Ramser function is $A(\log v_2 - \log v_1)$; it is not A nor $\log v_2$ nor $\log v_1$. The V.M. by a double process of insertion and elimination uses only $\log v_1$, and cannot, therefore, be said to be related to the Ramser function.

Consider any function whatsoever containing $(\log v_1)$ as a separate factor, *e.g.*,

$$F = A \log v_1 \overset{\pm}{\times} f(v_2, T_1, T_2, T_1/T_2, \text{etc.})$$

where F = arbitrary function and $f(v_2, T_1, T_2, T_1/T_2, \text{etc.})$ can take any form with respect to the temperature, pressure—and even the age of the operator !—obtaining at the time of the determination of v_1 provided these factors remain constant for L', H', and U, the three oils in question.

$$\text{Then } \frac{\text{V.M.}}{100} = \frac{\log L' - \log U}{\log L' - \log H'}$$

$$= \frac{A \log L' - A \log U}{A \log L' - A \log H'}$$

$$= \frac{[A \log L' \overset{\pm}{\times} f(v_2, \text{etc.}) - A \log U \overset{\pm}{\times} f(v_2, \text{etc.})]}{[A \log L' \overset{\pm}{\times} f(v_2, \text{etc.}) - A \log H' \overset{\pm}{\times} f(v_2 \text{ etc.})]}$$

$$= \frac{F_{L'} - F_U}{F_{L'} - F_{H'}}$$

Thus the V.M. by this method of adding certain quantities and then throwing them out or multiplying and then dividing by the same quantity—as in a certain well-known number-guessing game—can be said to bear a relationship to any function of type F we choose whatsoever. Some of these functions must, of necessity, be completely meaningless. Therefore it would be as logical to state that the V.M. is meaningless as to state that it is related to the V.T.R., because one of the functions F can take out of an infinity of functions is the V.T.R. Both statements are, in fact, not strictly true.

This point is particularly important to realize because, as I mentioned, the authors, whilst admitting the approximately additive nature of the Walther function and of the Independent Viscosity Index of Malschaert, " emphasize that the Walther function does not bear the simple relationship to the

function $1/v\,dv/dt$ and the $d \log v/d\,(1/T)$ . . . " supposedly demonstrated by the V.M. and ". . . consider this objection to be of sufficient importance for rejecting the I.V.I. in favour of the Viscosity Modulus." The Walther function and the I.V.I. may or may not have other deficiencies compared with the V.M., but it cannot be said that they compare unfavourably with the V.M. on this count. Finally, the whole mystical idea that a mere relationship to the V.T.R. is a strong point in favour of a function raises the question " Why then, not use the V.T.R. ? " The answer apparently, is the lack of another mystical property, *i.e.*, that of " natural homology "—by the V.T.R.

(3) *If the V.I. is a measure of the metaphysical property termed " natural homology " then the V.M. cannot claim to measure the same thing.* This statement is self-evident from Table VIII of the paper. It is included here merely to raise the question of what is meant by this " natural homology." It is not what chemists understand by " homology " and apparently not what physicists understand by it either. It must be a new concept then. To understand it we must define it. If we cannot define it we must, at least, point to an attribute by which we can recognize it. The V.I. apparently is such an attribute. Yet immediately we so characterize it we are asked to reject the V.I. in favour of some other attribute, the V.M., which does not agree with the V.I. numerically over any portion of the scale. That is why I call this property " metaphysical." It is indefinite in conception and apparently imprecise in its quantitative aspects. It is another emotive phrase which is difficult to discuss on logical bases for technical characterization of oils. Finally, what " natural homology " connects two oils of, say, 100 V.M., one having been well doped with a V.I. improver, whilst the other has been left without the advantage of this grafting operation on its family tree ?

Now, I am going to grant the authors the possibility that I am entirely misled in my arguments and that, indeed, the V.M. is additive, that it is peculiarly related to the V.T.R., which will be granted a fundamental status, and that it can further glory in revealing a " natural homology." Consequently, I will grant that even though each of Walther's, Malschaert's, Ramser's, and Dean and Davis's functions possesses one or two of these saving graces, none possesses all three as the V.M. does. Then another question arises, and it is this. Hardiman and Nissan's " n " is also based on log v, and by the arguments the authors used in deriving their equations (XLII) and (XLIII) (if these are admissible) it can be shown that the V.M. is simply a linear function of n. (I cannot claim originality for this statement, as I simply borrowed the authors' original derivation of the V.M., when they were still basing it on the Dean and Davis series. Then, they started with $\text{V.M.} = 100\,\dfrac{n_L - n_U}{n_L - n_H}$ and derived the V.M. without the complication of additivity and I acknowledge my indebtedness to them.) It follows therefore that n has (or lacks) all three attributes to an equal degree as the V.M. Then, why not adopt n ?

The authors make two criticisms of n. The first is that when $v_2 = 1$, then equation (XXXI) fails to depict the behaviour of oils, as all oils will appear to have the same viscosity at 100° F. This criticism was made and answered in 1945 in the discussion on the original paper when n was proposed.

Therefore, I will not discuss it further here and simply grant that equation (XXXI) for n must not be extrapolated below, say, 2 cs, its original lower unit. What happens, then, if equations (XX) and (XXI) are extrapolated below 2 cs? Do they give a reasonably coherent picture?

Equation (XX) informs us that Pennsylvanian oils of 1 cs at 210° F possess a viscosity of 0·96 cs at 100° F. This in itself is remarkable, but not as much as the other prediction that Pennsylvanian fractions of 0·87 cs at 210° F have zero viscosity at 100° F and finally that fractions, from the same series of oils with this notable "natural homology," which possess viscosities of 0·8 cs and less at 210° F have *negative* viscosities at 100° F. The industrial implications of such properties, if they were true, are simply enormous.

The answer to all these demonstrations is, of course, simple: we are dealing with essentially arbitrary systems. With such systems extrapolation is always dangerous and in most examples meaningless. In short, we have no business to extrapolate below 2 cs at 210° F if an empirical system is built with a specific lower limit of 2 cs. The authors must be aware of these facts and principles, because in discussing possible modifications in the L' and H' reference series which may be required in the future they state: "Any extension to viscosities below 2 cs at 210° F would, however, need to be examined in this respect."

The second "criticism" the authors make of n is that below 8 cs at 210° F, there are considerable differences between Dean, Bauer, and Berglund's data and results based on n "falling well outside the 'waves' characteristic of these series." This is, in fact, not a criticism, for they have previously shown the later extensions of the V.I. system by Dean and his collaborators to cover the range of 2 to 7·30 cs at 210° F were by two arbitrary steps, portions of which were not even defined by equations. As the whole work on n was an attempt to rationalize the V.I. system and thus to eliminate, amongst other anomalies, the arbitrary influences introduced into the system by the series of oils of $v_2 < 8$ cs which produce the "waves" characteristic it is, of course, not surprising that the results show differences in the region of maximum arbitrariness in the V.I. scheme. It is also not surprising that, as the authors demonstrate, in their Table VIII, the same results obtain with V.M. as with n. What is surprising is that whilst concluding that these differences when shown by n indicate that "...a series based on Hardiman and Nissan's equation and the constants mentioned above are not entirely satisfactory," Blott and Verver conclude that the same differences when shown by the V.M. indicate that "...the excessive sensitivity of the V.I. scale at its lower end has been diminished and its lack of sensitivity at the upper end remedied."

This statement that the V.M. is diminishing the "excessive sensitivity of the V.I. scale at its lower end" because for a value of V.I. $= -100$ gets values of V.M. ranging from -55 to -194 and for V.I. $= 0$ values for V.M. from $+19$ to -54 needs further clarification by the authors.

The V.M., as I see it, is simply this: it is the substitution of the logarithms for the absolute values of the viscosities in the V.I. system based on the non-standard curves by Hersh, Fisher, and Fenske instead of the standard curves proposed by Dean and Davis. Once we rid ourselves from ideas that this simple substitution of the logarithm for the absolute values

confers on the system any special "fundamental" virtue we shall be able to see the V.M. objectively and evaluate its contribution to this confused subject correctly. Thus, I shall start with the V.M. as an arbitrary modification of an arbitrary system and then attempt to answer the question: what has it to offer?

The V.M. offers most of what Hersh, Fisher, and Fenske offer in their tables: *i.e.*, a rational, though arbitrary, system of a V.I. which is continuously regular and which gives a single function of the viscosities at 100° and 210° F independently of the viscosity or the V.I. levels. As the logarithm is not additive in general, the V.M. cannot claim any superiority in principle over the original Hersh *et al* tables; in detail it is a nearer approximation to the additivity rule over a narrow range (probably of little significance in industry) than the original scheme.

The V.M. is very similar to n in behaviour, but it may claim an advantage over n as follows: n is fractional between 1 and 2 and decreases in value as the "quality" of the oil improves. The V.M. gives reasonable-looking numbers which increase as the quality of the oil improves. However, if n is to be modified to give something not too strange to eyes and ears accustomed to the V.I. I believe that the best modification of this arbitrary number is not by another arbitrary step but by the logical step of tying it up to the existing V.I. system. Obviously it is not possible to achieve complete congruence between the completely arbitrary V.I. system and any system that follows a mathematically constrained path. Therefore only partial coverage can be achieved. This was done with the Rational V.I. The authors choose to quote, in their Table V, two values for oils with $v_2 = 2$ and 3 cs, *i.e.*, at the extreme end of the most arbitrary step in the V.I. system and conclude that the divergence is so great between the R.V.I. and the V.I. that the system is "unsatisfactory." If this is so—and it may well be—then it is difficult to see how the V.M. which differs from the V.I. not only when $v_2 = 2$ and 3 cs but for all values of v_2 (see Table VIII) can be "satisfactory." I think that if n is to be modified I would still choose the arbitrary system of the R.V.I., which links it with the well-established V.I. over a considerable range, rather than the arbitrary system of the V.M., which connects with nothing in particular.

I find nothing else offered by the V.M. not already a part of most other systems advanced by different advocates.

Finally, I would like to give my personal views on what should be done in this field.

What is to be done by the petroleum industry in characterizing the viscosity–temperature sensitivity of lubricating oils will, naturally, depend on very many factors. The following recommendations appear logical to me:—

(a) *If the industry desires complete rationality, then it will be wise to reject the whole brood of indices, factors, numbers, moduli, etc., and adopt the specification of viscosity values at two or more temperatures to characterize the oils it manufactures and uses. In other words, the industry can adopt certain arbitrary temperatures as the ones at which viscosities are to be specified. This is because whatever system is adopted it will always be necessary to specify at least one viscosity value at a particular temperature plus some measure of the influence of temperature on viscosity. Thus there will always be a need of at*

least two viscosity measurements one of which will have to be quoted. Therefore, what I am suggesting is that instead of specifying one viscosity value plus a complex function of the viscosity at another temperature the second viscosity itself at this latter temperature be specified.

(b) *If the industry dislikes this straightforward method and wishes to pay homage to scientific workers in the field of viscosity by a gesture then it should adopt a system based on Ramser's function or the ASTM chart. It will still be necessary to measure viscosities at two or more temperatures, and it will still be necessary to be arbitrary in the adoption of temperatures, and the characteristics obtained will still be empirical with negligible significance scientifically.*

(c) *If the industry wants to adopt a rational though arbitrary system but still take advantage of the existing universal familiarity with the V.I. system, then the Rational Viscosity Index based on* n *and correlated with the V.I. over the maximum possible range should be adopted.*

(d) *If the industry feels that the most important aspect of any of these arbitrary systems is the familiarity of its members with the system, then the Dean and Davis system should be retained.*

(e) *If the industry wants a change which will not be directly connected with any of the systems used previously so that a complete break is made with present practice, but still desires to adopt a rational though arbitrary system, then the V.M. should be adopted. This suggestion will have the advantage that the V.I. had before,* i.e., *that of having at least one large industrial concern backing it. The history of the V.I. certainly suggests that this fact may be found, in the long run, of greater weight than all the others, and it should not, therefore, be dismissed lightly.*

MR BLOTT: I think that when Dr Nissan read our paper for the *n*th time he became hypnotized by *n*. I feel there are certain features of our scheme which he has not fully appreciated. He seems to think that the viscosity modulus is tied to the *n* value, which, of course, is not in the least true.

In Dr Nissan's scheme the lines for the two reference series intersect at a point corresponding with a viscosity at 210° F of 1 cs. He says that the reference series in the viscosity modulus scheme will also intersect. This, however, is not true. The two reference series in the V.M. scheme could be extended indefinitely, in the direction of lower viscosity, on the basis of empirical data, and it is obvious that oils having the same viscosity at 210° F from two series would not have the same viscosity at 100° F.

Dr Nissan's methods depend entirely on the fact that he has constrained the family of oils to fit a particular mathematical form, and this leads to the difficulty he has mentioned. In our scheme it does not matter whether we have a simple mathematical form of the series or not, we can use empirical reference series as I have indicated, and if we do not get anomalies with oils lying outside these reference series the scheme is satisfactory. Even the "waves" in the present V.I. series do not embarrass us much; we get satisfactory indices provided we base the index on a susceptibility factor that is approximately additive.

Going on from there, he says that the logarithm of viscosity is not strictly additive. We would say that there is no known function of viscosity that is strictly additive, but for our purpose the logarithm of viscosity is good

enough. It avoids anomalous indices, and it is a simple modification of the present scheme.

Then he says that oil blenders do not blend only those oils which have the same viscosity 210° F. Of course not. That is not our point. We use the logarithm of viscosity as an approximately additive function for the purpose of obtaining a rational basis for the definition of intermediate members of the family and members lying outside the reference series.

Again he talks of the Ramser function in relation to natural homology. But the Ramser function is purely a function of susceptibility, and has nothing to do with natural homology.

I agree with Dr Nissan, strangely enough, that, as regards susceptibility, if we measure viscosity at two temperatures we have got all the data we need. We have available the Walther equation, and although many people recoil with horror at the thought of taking double logarithms, because the units in which the viscosity is measured are then important, and they stumble over the constant a, it is still a very useful function. You can come fairly near to the viscosity of an oil at any temperature by extrapolating with the aid of this equation. (It should be noted that this may not apply to non-hydrocarbon lubricants.) I agree, therefore, that if we have two viscosities we can calculate the viscosity at any other temperature almost exactly, so that we then know the temperature susceptibility of the oil. But that does not classify the oil. The original V.I. scheme was to classify an oil when we knew its temperature susceptibility. That is also what we have tried to do. To make the scheme even more rational than Dr Nissan's, we do not force our reference series into an unnatural homology by demanding that they should fit any particular simple mathematical form.

N.B. Since the written communication of Dr Nissan differs in some respects from his verbal comments, the authors would like to deal with one or two points which were not raised at the meeting.

Dr Nissan states that, " It is essential to the argument . . . to show that the V.M. of any mixture of oils, no matter what viscosities they possess at 100° and 210° F . . . is an additive property." As will be seen by reference to the second part of the paper, this is, in fact, by no means essential. Actually, it is necessary to limit the argument to oils having the same viscosity at one temperature, but having different indices, since it is obvious that the index value assigned to mixtures of two components having different viscosities at both reference temperatures (say two oils of 100 V.M. with 10 and 50 cs at 210° F) will depend on the shape of the reference series.

In most cases encountered, however, mixtures of components differing both in index and viscosity will, in practice, show a considerably better additivity by the V.M. scheme than by the V.I. method. Thus, in the example quoted by Dr Nissan (oil A, 0 V.M., 50 cs at 210° F, and oil B, 100 V.M., 25 cs at 210° F), a 50/50 (vol) mixture proves, by calculation, to have a V.M. of about $55\frac{1}{2}$, whilst the V.I. works out at $69\frac{1}{2}$ instead of 50.

The reason why Ramser's V.T.R. cannot be employed for the same purpose as the V.M. is not due to any " mystical " properties of the latter, but to the very real fact that the former is a measure of temperature sensitivity, the latter a *classification* based on temperature sensitivity.

As the authors have shown, however, the V.T.R. can also be used for calculating an index equivalent to the V.M.

Dr Nissan demands a definition of the " natural homology," which was used by the authors in an (admittedly) somewhat vague sense. Though the concept may be somewhat imprecise—as many physical and chemical concepts are for which no exact measure is as yet available—it must not be assumed that the " natural homology " of oil series has no real meaning. This fact will be evident to all who have studied, say, the change in ring analysis of successive oil fractions. As Dr Nissan states, this property also finds expression in the V.I. (except in certain anomalous cases, as discussed in the paper), but this is no reason why the V.M. may not be used with the advantages enumerated for the same purpose. In many branches of natural science we can measure a magnitude by (say) a linear scale, but do the same thing better by employing a non-linear measure, such as a reciprocal or logarithmic scale.

A final remark will be made with reference to the examples calculated by Dr Nissan for 100 V.M. oils of very low viscosity (0·8 to 1 cs at 210° F) by Hersh, Fisher, and Fenske's equation (XX). It is obviously inadmissible to extrapolate an empirical equation to values for which it was not intended. Should the need for including oils of such low viscosities in the scheme arise, it would become necessary to modify the formula for the reference series to cover new empirical standard values. As already stated, the V.M. scheme does not depend on the precise definition of the reference series. The Hardiman and Nissan scheme, however, is dependent on the particular mathematical form of the reference series used, and anomalies at low viscosities therefore do constitute a barrier to a further extention of the R.V.I. into lower viscosities.

M. Roegiers : As a manufacturer of a concentrated oil which displays what is called to-day " V.I. improving characteristics," I felt perhaps more than many others the practical shortcomings of the present ASTM V.I. method.

For this reason I published (*Proc. 3rd Wld Petrol. Congr.*, 1937, **2**, 903) a graph similar to the authors' Fig 6, which shows that the V.I. system leads to anomalous values when applied to viscous oils. In other words, the present V.I. method gives the false impression that V.I. improvers are less effective on viscous oils than on thin oils.

Therefore I want to congratulate and to thank the authors for trying to correct that misbehaviour in a public discussion before this IP audience.

Although it is my intention to confine my remarks exclusively to the practical side of the problem, I would like to make one introductory statement, which has some theoretical importance for the point under discussion :—

(*a*) When dealing with viscosity-figures in fundamental physics, it is necessary to stick to viscosity n, as it results from the basic equation of Newton. This has the dimensions $[M \,.\, L^{-1} \,.\, T^{-1}]$, the C.G.S. unit of which is the " poise " (and not the " Stokes ").

(*b*) When reference is made to some additive function of viscosity of mixtures, as in equation (XXXVIII), it is necessary to state to which proportion-unit the blending proportions (percentage) refer.

(*c*) As to the authors' statement that "at the present time there is no known theoretical function of viscosity which is strictly additive," I have shown * that, for ideal mixtures—and these include the Newtonian refined petroleum fractions—the log η or log $1/\eta$ are strictly additive, provided the blending proportions of the component oils are *not* expressed in % *intermolecular attraction energy*.

(*d*) Furthermore, the fact that, for a specified binary ideal mixture, the ratio of the specific intermolecular attraction energies of the component oils No. 1 and No. 2—the viscosity-energy constant α in my binary blend formula †—does change with temperature, is one more reason why neither the V.I. system nor the proposed V.M. system could display strict additive or linear character. The later argument pro-

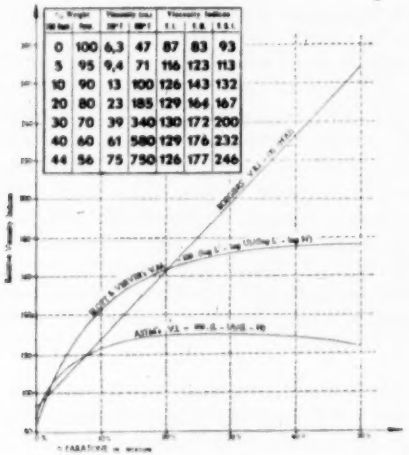


FIG A

RELATIVE VISCOSITY INDICES *vs* PER CENT PARATONE IN 200 SOLVENT NEUTRAL

vides the theoretical explanation why mixtures of a thin oil and a viscous oil, displaying both the same V.I. or V.M. value, do generally result in V.I. or V.M. values which are several points higher than those of the component oils.

How far, then, does the proposed "viscosity-modulus" affect the anomalous viscosity-figures referred to earlier. Looking at the V.I. curve and V.M. curve reproduced in Fig A, both curves referring to the same binary system (200 Neutral + Paratone), the improvement of the V.M. index over

* "Viscosités, Pressions de Vapeur, Tensions de Surface, Proportions d'Equilibre des Phases Liquide-Vapeur des Mélanges idéaux," *Bulletin de l'AFTP*, 80, Apr. 1950; *Petroleum*, London, 10, 11 and 12, Oct., Nov., Dec. 1949.

† $$\eta_{mixt} = \eta_2 \left(\frac{\eta_1}{\eta_2}\right)^{\frac{x.a}{x.a+(100-x)}}$$

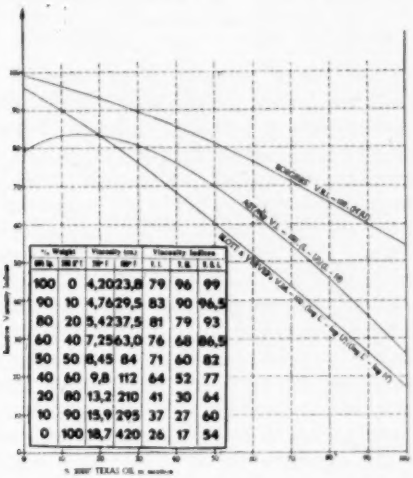
η_{mixt} = viscosity of a mixture containing x% (mass, or volume, or mole) of oil No. 1 of viscosity η_1, and $100 - x$% oil No. 2 with viscosity η_2.

the V.I. index is partial only. Both curves suffer from the same basic defect : instead of rising more or less linearly as a function of the Paratone content, they both curve to a maximum value and then go down.

The reason for this defect, which is common to the V.I. and the V.M. equations, is that the *U* oil in both cases refers to *two* reference series, *H* and *L* (or *H'* and *L'*), and that the resulting iso–V.I. lines (or iso–V.M. lines) of the reference series (0 to 100), when drawn on a graph with log co-ordinates, are *divergent* instead of being paraliel (see the authors' Figs 6 and 7).

How can we cure such a defect ?

Disregarding the existence of the *L* or *L'* series—the oils of which no longer deserve the reputation of displaying the poorest viscosity–temperature



% Weight		Viscosity cSt		Viscosity Indices		
885 S	885 F	100° F	210° F	V.I.	V.R.	V.R.I.
100	0	4,202	3,8	79	96	99
90	10	4,76	29,5	83	90	96,5
80	20	5,42	37,5	81	79	93
60	40	7,25	63,0	76	68	86,5
50	50	8,45	84	71	60	82
40	60	9,8	112	64	52	77
20	80	13,2	210	41	30	64
10	90	15,9	295	37	27	60
0	100	18,7	420	26	17	54

FIG B

RELATIVE VISCOSITY INDICES *vs* PER CENT 2000 TEXAS OIL IN 885 SPINDLE

curve among the mineral lubricating oils—and compare the viscosity at 100° F of the *Y* oil to the corresponding viscosity of the present ASTM *H* series, eventually straightened to a *H'* series, and calculate, for the *U* oil under consideration, the ratio $(H/U) \cdot 100$. The resulting "relative viscosity–index" might be called "Penna Viscosity-ratio (P.V.R.)" or "Viscosity–Ratio Index" (V.R.I.). Its figure means that "at 100° F the kinematic viscosity of the corresponding Penna oil (*H'* oil) is V.R.I.% of the viscosity of the *U* oil." Thus the well-known and excellent Penna oils would conserve their previous "100" value. Although the "zero" value will no longer be reached by the poorest oils, the present V.I. rule, "the poorer the oil the lower the index, or vice versa," will be maintained. This new index would apply to any oils (mineral, vegetable, and ester oils), even to such liquids as silicones, provided they display Newtonian behaviour at the two standard temperatures 100° and 210° F.

What is more important, is that all the resulting iso-V.R.I. lines, when

drawn on a chart similar to that of the authors' Figs 6 or 7, will now be parallel to the *H* or *H'* line. Bearing in mind one of the corollaries of my blending-formula for binary oil mixtures, the V.R.I. curve of all systems similar to the paratone blend, just like those of any other binary quasi-ideal system (Fig B), will now display on the chart in question an approximate linear behaviour (Fig C). This is plainly confirmed by the V.R.I. blending curve illustrated in Figs A and B. In other words, the proposed V.R.I. equation is very much nearer that " additivity " the authors are looking for.

Its extreme simplicity in calculation and the avoidance of the use of a

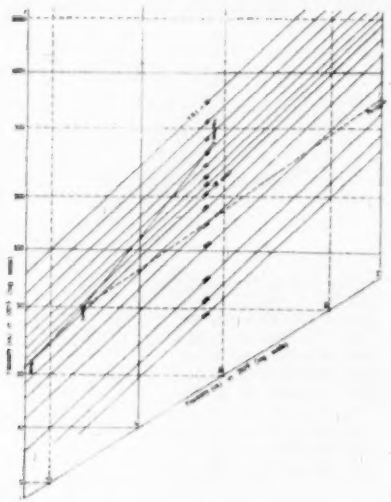


FIG C

ISO-V.R.I. LINES FOR OILS OF 4 TO 75 CS AT 210° F

— — — Mixtures of 200 neutral + Paratone (Fig A)
. . . . . Mixtures of 2000 Texas + 885 spindle (Fig B)

logarithmic table, makes the V.R.I. method of value to the oil users as well as to the oil technologists. It is well worth forgetting the so-called lack of " natural homology " which is sometimes arbitrarily claimed for the present iso–V.I. system.

A further advantage of the proposed V.R.I. method is that for very thin oils the calculated value is less sensitive to small experimental errors of viscosity measurements than the present V.I. method, and much less than the suggested V.M. method. Taking into account the standardized tolerance of 0·2 per cent on kinematic viscosity measurements (ASTM–D. 445–46-T), the figures in Table II will illustrate that fact.

Why should not the ASTM change the standard temperature for V.R.I. calculations (100° and 210° F) to the freezing and boiling points of water (32° and 212° F) and adjust the *H'* series accordingly.

TABLE II

	Viscosity at 210° F cs	Viscosity at 100° F cs	ASTM V.I.	Blott and Verver's V.M.	Roegiers' V.R.I. (ref. to *H'* series)
1. Theoretical viscosity	2	6·8	91·5	100	100
2. Error of +0·2% on viscosity at 210° F .	2·04	6·8	102	128	103
3. Error of −0·2% on viscosity at 100° F .	2	6·66	98	114	102
4. Cumulated errors for 2 and 3. . .	2·04	6·66	109·5	141	105
Extreme differences for similar errors . .			18 points	41 points	5 points

MR VERVER: In reply to M Roegiers, in the first place I may mention that, in taking the additivity of the log values, we did consider percentage by volume, because in blending I think it is usual to take the percentage by volume. Again, this is very approximate, but it is accurate enough for our purpose, as Mr Blott has said. We have considered only iso-viscous mixing, *i.e.*, the mixing of oils of the same viscosity level, and I must stress the fact that the additivity of the index which we have considered applies only to that case. M Roegiers has taken the case of an 885 spindle oil and a very much thicker oil, and to our minds it stands to reason that no index will give additive figures for those oils, for the very simple reason that if you take a thick and a thin oil in the same series, say the V.I. = 100 series, mix them and make a comparison with an intermediate oil from the same series, having the same viscosity as the blend, the viscosity susceptibility of the two samples will not be the same; the slope of the line for the intermediate oil will be steeper than that of the mixture.

Then M Roegiers has taken as an example the addition of a V.I. improver. I can readily understand his interest in this subject as a manufacturer of a V.I. improver. But to my mind it is not a very good example to take, since the fact of mixing an oil with a V.I. improver may introduce the complications of a colloidal system. Is it a necessary criterion of a viscosity index that a mixture of an oil and a V.I. improver should give a straight line on M Roegiers' chart? We are dealing here with non-Newtonian flow, and I would prefer to limit the discussion to liquids which do display Newtonian flow.

With regard to the proposal to use a single reference series, by doing this we depart, as M Roegiers has said, from the idea of basing our scheme on the behaviour of a natural oil family. M Roegiers has one series, but it does not follow that an oil having another index by his scheme will correspond to a natural oil series. I think we can say definitely that they will not correspond.

MR BLOTT: I would add to what Mr Verver has said. M Roegiers' family would be based on a single member. We have at least a mother and father in our family, in the *L* and *H* series, but he is dealing with a single member, and I do not think we should get the same sort of family.

Then he takes H/U as his index. This will give an index which is not additive, and I have already shown that there is a fundamental reason why dv/dT should be additive, which means that the viscosity index should also be additive. We should like to add a note to our paper incorporating this generalization showing the fundamentally additive nature of dv/dT.

DR G. W. NEDERBRAGT: One of the main arguments of the authors against the present Viscosity Index is that the method for interpolating between the two standard curves leads to difficulties because the viscosity itself is not additive in mixtures. In their opinion a function of viscosity which is additive in mixtures should be used.

The viscosity of mixtures is rather complicated because we have to deal with long, flexible molecules like paraffins and also with compact, rigid molecules like polynuclear aromatics and naphthenes. We cannot even be sure that the mixture of two equi-viscous components has the same viscosity.

In some measurements made in Amsterdam with mixtures of the more or less equally viscous hydrocarbons *cyclo*-hexane and *n*-decane, the viscosity was noticed to drop by about 6 per cent. With mixtures of the more or less equally viscous *n*-hexadene and methyl naphthalene, the drop was found to be about 13 per cent.

The same may occur with oils, and this means that no function of viscosity alone will ever be found that is satisfactory in all cases. When, however, we tolerate deviations of several per cent, there are a number of empirical formulæ.

For widely differing viscosities of the components the log–log formulæ are better than the log formula, indeed we found a linear relation between volume fraction and log–log (viscosity in millistokes) useful in many cases. In the case of Mr Blott and Mr Verver, however, the viscosity differences are moderate, and then the log formula is as good as the more complicated one and is more attractive because it is not dependent on the unit of measurement.

T. M. TAYLOR: The present difficulties with the V.I. system arise in part from attempts to extrapolate beyond the high reference series which was originally selected on the basis of materials then commercially available. Similar problems have arisen in the determination of octane number due to many present-day gasolines having superior anti-knock properties to the original high reference fuel. It is therefore advisable to consider the various systems for expressing the viscosity/temperature relationship of lubricants not only with reference to currently available materials but also allowing for future developments. I would therefore like to make some observations as to how "ideal" oils, *i.e.*, which do not change in viscosity with change in temperature, would be rated in some of the systems that have been proposed from time to time. In Table I the authors compare two lubricants with almost identical viscosities at 100° F, but differing in viscosity at 210° F, and yet having the same V.I. according to the existing method. The anomaly can be further emphasized by including a third oil, at present only a hypothetical "ideal" oil, which does not change in viscosity with change in temperature. An oil of this type with a viscosity

of 90·9 cs at both 100° and 210° F would have a V.I. of 138, which is lower than that of both the silicone and the ester, despite its very apparent superior viscosity/temperature characteristics. The reasons underlying this have been explained by the authors, and can be appreciated from Fig 6. According to the proposed V.M. system, the ester, silicone, and " ideal " oil would have V.M.s of 206, 308, and 370 respectively.

Continuing with thoughts on " ideal " oils, it is of interest to compare the present V.I., the Rational V.I. of Hardiman and Nissan, and the viscosity modulus of such oils over a range of viscosities likely to be encountered in practice. According to the Dean and Davis system, the V.I.s of such oils will increase from 135 up to 360 in the range 200 to 4 cs. Below 4 cs there is a marked change in the curve, and for lower viscosities the V.I. remains at approximately 365. In passing, I would mention that these figures are all anomalous; as will be seen from Fig 6, they lie on the V.I. curves which have turned back on themselves, and on this part of the curve for a given viscosity at 210° F an increase in viscosity at 100° F represents an increase in viscosity index, which is absurd.

The curve relating viscosity modulus to the log of viscosity for the " ideal " oils is of similar shape to that for V.I. against log viscosity, but without the sharp break at viscosities below 4 cs. In line with the authors' claim of improved sensitivity for oils of good viscosity/temperature relationship, the viscosity modulus figures are considerably higher than the V.I.s, increasing from 350 to 1000 over the range 200 to 2 cs. It would, however, seem both logical and neater for the " ideal " oils, the viscosity of which does not alter with temperature, to have a fixed viscosity-index modulus (or call it what you will) which is independent of the viscosity, and I would be interested in the authors' views on this point. In this connexion, the rational viscosity index as proposed by Hardiman and Nissan does go a long way to meeting this suggested requirement, for between 200 and 2 cs the R.V.I. is about 190 to 215.

It can be shown by plotting viscosity modulus against log of viscosity at 210° F for : (*a*) the " ideal " oils, the viscosity of which is independent of temperature, and (*b*) the oils giving the maximum viscosity modulus as calculated from equation (LI), that the two curves converge in the region of 3–4 cs, *i.e.*, at this viscosity level the " ideal " fluid has the maximum viscosity modulus, but that at viscosities both above and below 4 cs, fluids which increase in viscosity with increase in temperature could be rated by the V.M. I would like to ask the authors if this touching of the curves at 4 cs has any special significance or whether it is just pure chance, and whether they would see any advantage in a system where the " ideal " fluids at all viscosity levels give the maximum viscosity index or modulus figures.

MR BLOTT : I think the point raised by Mr Taylor is perhaps more simply considered in terms of an index based on dv/dT, where we have the situation shown in Fig D.

Here the " ideal " oil, where $dv/dT = 0$, corresponds with an index of the order of 500, but changes with viscosity level. This anomaly is due to the particular reference series used. Mr Taylor has said that it does not vary to the same extent with the Hardiman and Nissan series. That is so. With-

out being so rigid as Dr Nissan, however, we could modify the *L* or the *H* series to make the index the same for " ideal " oils at all viscosity levels, but whether we would be justified in doing this I don't know. If the idea of the family of oils means anything, the reference series should not be arbitrarily modified to deal with some hypothetical case.

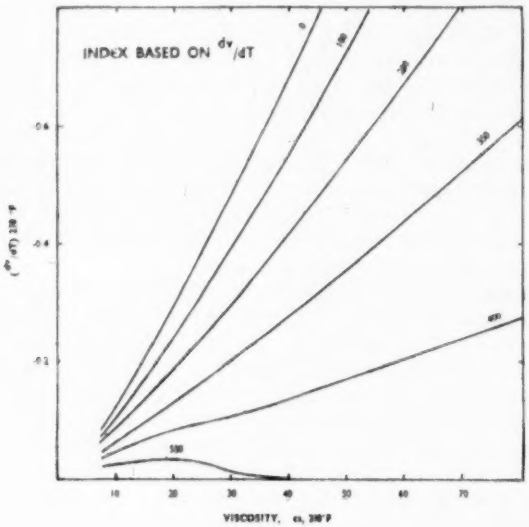


FIG D

The hypothetical oils which show no change of viscosity with temperature would not be hydrocarbon oils. If such oils do not fit in with the present scheme, we shall just have to accept that they do not.

DR A. H. NISSAN : The authors are now saying that ideal oils should not be discussed in judging the V.M. because they are not hydrocarbons. I do not think that this is a fair plea, since they themselves have admitted the discussion of non-hydrocarbon oils in justification of the V.M. system. In the discussion of Table I, for instance, it is stated that the ester-type and the silicone-type oils can have different viscosity values at 100° and 210° F respectively but still give the same V.I., and this fact is cited as condemnation of the V.I. system. It is later shown that on the V.M. system such oils will give different values, and this fact again is cited as a justification for the V.M. If non-hydrocarbon systems are to be excluded from our considerations they should be systematically and consistently kept out; otherwise the discussion of these systems is perfectly legitimate.

MR BLOTT : I have indicated that we should be very happy if the " ideal " oil fitted in the present scheme. As it is, the " ideal " oil would not have a constant index at all viscosity levels, and in that sense it would not fit in. We should not, however, get the type of anomaly shown in Table I, where

two oils, for the same index number, have the same viscosity at 100° F, but very different viscosities at 210° F.

T. M. TAYLOR : If you take as reference series : (*a*) the present *H* series with a V.M. of 100 and (*b*) oils which do not change in viscosity with change in temperature having a V.M. of 475, would there be very marked differences on the V.M. of the present *L* series (0 V.I.) over the range of viscosities normally encountered.

MR BLOTT : I have made a calculation for one case, based on the present I.P. series, to find how far the L line must be shifted on Fig D with the H line as at present, to give a constant index of 475 for $dv/dT = 0$. The new reference series calculated in this way would correspond with an oil series of lower V.I. than the present *L* series by amounts as illustrated below :—

v 210, cs	V.I. of calculated series relative to present *L* series
10	−62
20	−34
40	−25
70	0

I do not know whether you think that this represents a very considerable change in the series or a minor change that could be tolerated.

C. E. MOLD : As a result of listening to the discussion, we are left rather with an impression that a reasonable scheme of viscosity index or modulus, or what have you, can be devised, provided extraordinary limitations are imposed on what we do. Apparently we have to avoid making any estimates of what will happen if we blend two oils having dissimilar viscosities at 210° F; we have to try to avoid any ideas of what will happen if we add too much in the way of non-hydrocarbons, and so forth.

Surely, from the practical point of view, what we want is something that will give a reasonable good result, bearing in mind the developments now taking place. If silicones and esters are coming into favour, the viscosity index must still enable us to do a certain amount of rough-and-ready prediction. I do not think it will be of great practical value to work out something which will give beautifully smooth curves if the variations are not very great.

MR BLOTT : I appreciate Mr Mold's point of view on this matter. We would all like to see some scheme whereby we had a simple additive law for oils of different viscosities and different indices. But as Dr Nederbragt has pointed out, even when we consider viscosities alone, we have anomalies. If we blend two oils of the same viscosity we may not get a blend of equal viscosity, and in asking for complete additivity in the index on blending oils of different types and viscosities, I think we are asking for the impossible. It depends, of course, on what we mean by this additive

law. What I mean by it is that when we take A parts of an oil with an index $(VM)_A$ and B parts of an oil with an index $(VM)_B$ we get an index given by

$$\frac{A \times (VM)_A + B \times (VM_B)}{A + B}.$$

We may be able to calculate the viscosity or the index of the mixture, but it would not take that simple form.

C. I. KELLY: I feel it necessary for some emphasis to be put on the point that we are perhaps expecting too much of the lubricating-oil industry *as a whole* by asking it to accept any V.I. system for *general* use which is proclaimed to be superior to those that have gone before, because it is based on the additive-blending of two series of hydrocarbon oils, one of high and one of low V.I.

Mineral oils generally do not obey the additive-blending law, though some selected pairs can for certain purposes be regarded as obeying it approximately, if certain functions of the oils' iso-thermal viscosities, expressed in certain units of viscosity, are employed.

But the lubricating-oil trade is interested in the behaviour of not solely two selected series of hydrocarbons when blended but in the blends of widely different mineral oils and in their blends with many saponifiable oils and also heterogeneous additives, some of which are soaps. And a few of these disparate components of "ready-for-use" lubricants will obey an additive-blending law when the same functions of the components' iso-thermal viscosities are used in the calculations. Many pairs of these components, used in practice, mix in the most amazing of ways far removed from the additive-blending law. This is one point.

There is another difficulty. In the use of V.I. systems it is supposed that the particular oil or complex blend has a straight-line viscosity–temperature curve when specified functions of the viscosity values expressed in chosen units are plotted against a chosen function of the temperature. It is this, more perhaps than the former, above, which may be a source of erroneous thought accepted as accurate by a young man entering the industry, who would perhaps have the true position of fact obscured by the (to be generally accepted) thoughts that: such viscosity–temperature curves are straight, that V.I. systems reflect the v/t relationship of such oils over a wide range of temperatures encountered by the oil in practical use.

The authors are aware of this as seen in Section 2, where they refer to viscosity index as V.I. T_1/T_2 "where T_1 and T_2 are the two temperatures to which the index is intended to apply." In this it is implicit that an oil may have many different V.I.s, as indeed they have, according as T_1 may move into the high range of operating temperature and T_2 descends into the lower range in which the oil may become a "glass" or a very plastic paste because protective colloids function.

Whichever V.I. system is used, or a corrected version of an older one, the quoting of V.I. or V.M. should always be accompanied by a quoting of viscosities at several widely differing temperatures so that the user of the V.I. or V.M. may readily, by plotting, learn whether the indices are real or anomalous. Thus, we shall be quite sure where we are going with old or

new V.I. systems and leave no doubt as to how much interpretation the indices of " ready-for -use " lubricating oils can bear.

MR VERVER : I think I can say that the majority of mechanical parts in use to-day are still lubricated mostly with mineral oils, and therefore the petroleum technologist is inclined to think in terms of mineral oils, to regard them as, so to speak, the basis of his thoughts. Therefore, I think it is rather natural that, since these constitute the majority, he tries to simplify his thoughts by converting these things into a straight-line form for all oils. Were the position to change, so that the majority of bearings were lubricated with silicones or organic esters—I do not think there is an immediate prospect of that—he would have to base his thoughts on those, and then possibly the mineral oils would become the anomalous cases. That is the point I want to make.

THE CHAIRMAN, having invited further contributions in writing, said : We have listened to an extremely interesting discussion on what has always been a very complex and controversial subject ; I think it is fair to say that it is still complex and controversial and is likely to remain so for quite a long time. As has been suggested in the discussion, we shall never arrive at an ideal solution until the ideal equation for expressing viscosity–temperature variation has been derived. It will have to be a two-constant equation to give what we require. Until such an equation has been developed we must content ourselves by adopting the most practical and convenient scheme for our ordinary everyday purposes.

It remains for us now to thank Mr Blott and Mr Verver for their extremely interesting and stimulating paper ; and I would add our thanks also to Dr Nissan, M Roegiers, and all who have contributed to an interesting and very lively discussion.

(The vote of thanks was accorded with enthusiasm.)

WRITTEN CONTRIBUTIONS

DR P. J. UDALL : Part I alone makes the paper a very valuable one to those interested in the subject, and whilst the writer is not wholly in agreement with the proposals suggested in Part II, the authors have evidently given a great deal of thought to the subject. The excellence of this paper on such a very controversial subject is, however, bound to stimulate criticism and comment.

With the increase in demand for synthetic material to cover wide temperature ranges the Services are anxious that a method of expressing viscosity/temperature relationship of wider application than the Dean and Davis V.I. should be developed with the backing of the IP and by general agreement with industry. It is hoped that this paper and the comments received will assist the Standardization Committee to put forward an acceptable system in the very near future.

Although it is realized that lubricants are still predominantly produced from petroleum fractions by conventional refining methods, in the cases where the viscosity/temperature relationship is of the most importance synthetic materials are being introduced to an ever-increasing extent.

Furthermore, the petroleum industry's experience in the field of lubrication and the fact that raw materials for non-hydrocarbon lubricants are often derived from petroleum would suggest that the petroleum industry will be deeply involved; some oil companies are in fact already producing and marketing non-hydrocarbon lubricants. It is evident, therefore, that it would be desirable, in deriving a viscosity/temperature coefficient which is to replace the Dean and Davis viscosity index, to consider non-hydrocarbon materials equally with hydrocarbon materials. Many of the advantages put forward for Viscosity Modulus apply only to hydrocarbon oils. For this type of material the change is not considered justified; the present system is satisfactory and well understood, having regard to the fact that it is a technological rather than a strictly scientific tool. From this point of view many of the criticisms levelled at it touch on rather minor points, and it is doubted whether the people on most familiar terms with V.I. have found the shortcomings of the system any serious inconvenience for normal petroleum products.

Replacing a V.I. by V.M. means a change in the numerical value of the viscosity/temperature coefficient for virtually all lubricating oils and hydraulic fluids. Any change of this type requires an effort of mental readjustment for those used to the old system, and it should therefore be far reaching and of the maximum usefulness to be worthwhile. It is suggested that the proposed change does not go far enough, as there does not appear to be sufficient justification for basing a system, which it is hoped will be satisfactory for a wide range of materials, on the old reference standards which themselves are based on the properties of one type only of these materials. Why should correlation with a "natural homology" be considered an advantage when lubricants outside this classification, such as synthetics and polymer-loaded mineral oils, provide the difficulties? Furthermore, such correlation is becoming increasingly more artificial as the hydrocarbon oils themselves are being subjected to more extensive processing. The fact that some lubricants still have a negative value on the V.M. scale seems unnecessary, and is again the results of preserving old reference standards which are somewhere in the middle of the range as regards viscosity/temperature behaviour. A factor depending on the general mathematical form of the viscosity/temperature relationship rather than on any particular arbitrary standard liquids would seem more logical and would most likely lead to a more permanent and acceptable solution of the problem. Moreover, such a factor would probably be definable over any specified temperature range; this would be a considerable advantage because of the extreme temperature conditions now having to be catered for.

All the above considerations indicate that the basing of any new system on the 0 and 100 values for two series of crude-oil fractions does not have the same justification as when V.I. was first proposed. A method applicable equally to all fluid lubricants is required, and the fact that a system ignores the "natural homology" occurring in lubricating-oil series should not be a reason for its rejection.

In reply to Dr Udall, the authors wrote: The authors would like to emphasize the fact that what is required in practice is not only an ex-

pression for the temperature sensitivity of lubricants, but also a *classification* in relation to a known standard. It is, of course, an easy matter to express the temperature sensitivity in an adequate manner—a statement of viscosities at a number of temperatures would suffice. In practice, however, two points arise :—

(*a*) an involuntary comparison with oils of known behaviour is always made, and
(*b*) an expression of this comparison in a single figure is required.

These facts necessitate the use of at least one reference series. So long as petroleum oils constitute the bulk of the lubricants used it seems logical to base the reference series on such mineral lubricants.

Dr E. W. Dean : Messrs Blott and Verver have made a valuable contribution to the published literature on the subject; whether or not their specific proposal receives broad acceptance.

My limited study of advantages and disadvantages of the use of the logarithmic formula has not led to any firm conclusions. Its practical disadvantages are obvious, and I cannot find that the authors have included an adequate exposition of what I think may be its greatest practical advantage. This has been discussed under the subject of " anomalies," but it has not been explained that the anomalies of the V.I. scale are somewhat rare, extreme examples of a defect which already has assumed practical importance. We do not have a " natural homology " to guide us in dealing with some of the oils which are now broadly used, but we know that 150 V.I. is as easily attainable in the low-viscosity range as 120 V.I. in the high range. The authors probably have not solved this problem more effectively than did Hardiman and Nissan, who, incidentally, claim applicability " to an infinite range of viscosity–temperature characteristics " but portray an anomaly in Fig 5 of their paper (*J. Inst. Petrol.*, 1945, **31**, 255). However, the mathematics of the authors are simpler than those of Hardiman and Nissan, which is an asset.

I think the greatest weakness of the proposed " V.M. " system is the choice of the basic values of Hersh, Fisher, and Fenske. The defects of these values are indicated in Table I of the 1940 paper by Dean, Bauer, and Berglund, even though they were not discussed in the text. The " patchwork " nature of the basic values of the V.I. system is admittedly undesirable, but is the result of a carefully considered decision. The scale was some ten years old in 1940, and it seemed better to sacrifice the artistic effect of the curves then to invalidate the considerable body of data already on record.

The preceding paragraph reflects a personal and possibly prejudiced opinion. There is, however, no question regarding the broad acceptance and use of the basic values of the " V.I." scale and the limited familiarity of the petroleum industry with those of Fenske. It seems possible that the " V.M. " system might receive general acceptance more readily if it had the same reference basis as the V.I. scale.

In reply to Dr Dean the authors wrote : In replying to the points raised it may be as well to emphasize that :—

(*a*) within wide limits the unambiguous classification of lubricants in the V.M. scheme is not dependent on the adoption of any particular reference series;

(*b*) any function of viscosity that is approximately additive may be used in calculating the V.M.

Both these points are dealt with in the paper. The question of the choice of reference series is discussed, particularly, on p. 218, and the question of the additive function of viscosity is mentioned on p. 215. The need to use an additive function of viscosity or, more generally, an additive function of the susceptibility factor is supported by the generalization that was introduced by the authors in presenting the paper and is now added as a note to the original text.

The authors suggested the adoption of the Hersh, Fisher, and Fenske reference series because these values were free from the " waves " of the Dean, Bauer, and Berglund series, while the logarithm of viscosity was suggested because it appeared to be simple but adequate. The suitability of the V.M. scheme in principle should not be judged, however, by this somewhat arbitrary choice.

L. GRUNBERG : I wish to comment mainly on the material not contained in the preprint, but submitted by the authors directly to the meeting. The authors seem to have been uncertain about the force of their arguments on the importance of homology and additivity. The new material does not improve the position. The triangular diagram which shows the importance of homology with regard to the chemical constitution does not prove its importance with regard to viscosity–temperature susceptibility. In order to prove the latter, the authors should have shown, on the same diagram, lines of equal susceptibility expressed as V.I., V.M., or dv/dt. If they had done this they would probably have found that homology has no bearing on viscosity–temperature susceptibility. I think they would also have discovered that the chemical constitution of Pennsylvanian oils is not typical of most 100 V.I. oils used at present. This emerges from a table given by van Nes and van Westen (" Aspects of Constitution of Mineral Oils," Elsevier, 1951, p. 404).

The authors now state dv/dt at 210° F to be of greater significance than the viscosity–modulus. dv/dt is a function which can be calculated by assuming, for instance, that the exponential viscosity formula applies. There seems to be no reason why this function should not be chosen in preference to the viscosity–modulus proposed in the original paper.

In reply to Dr Grunberg the authors wrote : It may be stated that on a triangular diagram showing the composition of mineral oils by the ring-analysis method as shown at the meeting, lines of equal temperature susceptibility may roughly be drawn for oils of approximately the same molecular weight. (The equivalent calculation for aromatic-free oils is referred to in the paper, ref. 28.) The correlation will admittedly be a rough one, however, since isomerism will tend to upset matters in specific cases as in the instance of the Pennsylvanian oils referred to by Dr Grunberg. A general average regularity nevertheless exists.

Dr Grunberg seems to show some confusion of thought in suggesting that the authors now state dv/dT at 210° F to be of greater significance than the V.M. The value of dv/dT is a measure of temperature susceptibility, while the V.M. is an index number in a scheme of classifying the lubricant according to its temperature susceptibility. It is clear therefore that, in the present connexion, there can be no question of the relative significance of these two quantities. In effect, the value of dv/dT is used in calculating the V.M.

J. L. TAYLOR: I have read Messrs Blott and Verver's paper with great interest and congratulate them on their ingenuity in using the logarithm of the Viscosity Index to smooth out irregularities in curves based on the property itself. It was, incidentally, Arrhenius who discovered that the logarithm of viscosity was an additive quantity.

One of the very large numbers of methods for expressing the viscosity–temperature characteristics of oils by a single figure, used even prior to 1929 and still in constant use, is, of course, the simple ratio of the viscosities at two temperatures. I wonder whether it is generally realized that a simple relationship exists between the ratio of the Redwood Viscosities at 70° and 140° F and also at 140° and 200° F and the Dean and Davis V.I., sufficiently precise for most practical purposes. A copy of a chart for making these conversions is available.

Meanwhile I shall watch with interest to see what success attends the adoption of the proposed Viscosity Modulus system in preference to Dean and Davis's, which was described to me in 1935 as a "dying horse."

SOME VIEWS ON THE SAE VISCOSITY CLASSIFICATION

By J. G. Withers (Fellow) *

Introduction

The SAE viscosity classification for automotive lubricating oils has proved so successful in defining marketed products that it is now used exclusively in most parts of the world. Amendments have taken place from time to time, but the basic structure has remained substantially unaltered for about twenty-five years.

In the opinion of the author there are, however, some inconsistencies, omissions, and unnecessary complications in the SAE classification as at present published,† and one of the purposes of this note is to suggest minor modifications, which, it is believed, overcome these faults.

There are two requirements to be considered in the selection of the viscosity of lubricating oils for automotive purposes: first, that the viscosity shall be suited to the working temperatures, and secondly, that it shall not be excessive at the starting temperatures. A further purpose of this note is to make general recommendations for the viscosity grades appropriate to different atmospheric temperatures.

Engine Oils

The essential features of the SAE viscosity classification for engine lubricating oils, as revised in October 1950, are reproduced in Table I; this revision became compulsory in April 1952 and the earlier revision obsolete. The temperature of 210° F is now used for classifying the working viscosity of all oils, and 130° F has been abandoned as a control temperature. Where applicable, the viscosity under low-temperature-starting conditions is specified at 0° F.

Working Temperature

Estimates of the temperature limits in automobile engines under fully warmed-up conditions are as follows; the ranges are large because they depend on the design, climate, and type of duty:

Oil in bearings	140°–300° F
Cylinder wall—bottom . . .	200°–300° F
Cylinder wall—top	260°–400° F

The ideal control temperature for the working viscosity is about 250° F; nevertheless, the 210° F given in the SAE classification, which is the highest of the U.S. standard temperatures for viscosity determination,

* Anglo-Iranian Oil Co. Ltd., Sunbury Research Station.

† "SAE Handbook, 1951," Society of Automotive Engineers, New York.

although below the ideal, is an acceptable compromise between the lowest and highest operating temperatures. The decision to abandon 130° F, where previously applicable, in favour of 210° F is therefore justified on technical grounds as well as on the grounds of the convenience of a common temperature for all grades.

The SAE system is based on Saybolt viscosities with centistokes as an alternative; but the latter are preferred, being absolute units which are internationally acceptable. It is recommended, therefore, that centistokes at 210° F are generally adopted as the working viscosity of motor oils, and that steps are taken to eliminate the use of other viscosity units and other temperatures.

Starting Temperature

Extrapolated viscosities at 0° F are specified for the " W " grades (see Table I) to cover starting conditions. These extrapolated viscosities may not be a close estimate of the true viscosity when the oil is close to its pour point, but nevertheless the limits given provide a reasonable safeguard over low-temperature viscosity. It is clear, however, that a suitable pour point must also be specified, and it is suggested that this should be at least 15° F (8° C) below the lowest expected starting temperature. The combination of extrapolated viscosity and pour point is believed to be at least as satisfactory as determined low-temperature viscosity, and much more convenient.

TABLE I

SAE Engine Oil Classification (Effective October 3rd, 1950).

SAE Viscosity No.	Viscosity range							
	At 0° F				At 210° F			
	Minimum		Maximum		Minimum		Maximum	
	cs	Saybolt sec	cs	Saybolt sec	cs	Saybolt sec	cs	Saybolt sec
5W	—	—	871	4,000	3·88	39	—	—
10W	1,307 (a)	6,000 (a)	2,614	Less than 12,000	3·88	39	—	—
20W	2,614 (b)	12,000 (b)	10,458	48,000	3·88	39	—	—
20	—	—	—	—	5·75	45	9·65	Less than 58
30	—	—	—	—	9·65	58	12·98	Less than 70
40	—	—	—	—	12·98	70	16·82	Less than 85
50	—	—	—	—	16·82	85	22·75	110

(a) Minimum viscosity at 0° F can be waived if viscosity at 210° F is not below 40 sec Saybolt Universal (4·2 cs).
(b) Minimum viscosity at 0° F can be waived if viscosity at 210° F is not below 45 sec Saybolt Universal (5·75 cs).

A general guide to limiting starting temperatures for oils which just meet the maximum viscosity limits at 0° F, taking into account loss of battery performance at reduced temperatures, is given in Table II, together with maximum pour points appropriate to the limiting temperatures. For the British climate, however, pour points below 0° F are not required.

Viscosity index cannot be recommended as a control for the extrapolated maximum viscosity at 0° F since the value necessary depends on whether

TABLE II

SAE Viscosity No.	Limiting starting temperature, ° F	Pour point, ° F Max
5W	−10	−25
10W	0	−15
20W	+15	0

the viscosity at 210° F is close to the lower limit or well above it. As a general guide, however, the following minimum V.I.s apply to the proposed mid-viscosities given in Table III: 5W, 95; 10W, 65; and 20W, 60. If the viscosity at 210° F is at the lower limit, considerably lower V.I.s can be used.

TABLE III

Rationalized SAE Viscosities for Engine Oils

SAE Viscosity No.	Viscosity at 210° F, cs		Approximate Redwood No. 1 sec at 140° F for proposed mid-viscosity at 210° F (90 V.I.)	Extrapolated viscosity at 0° F is satisfied if cs 100° F/cs 210° F is not more than
	Proposed mid-viscosity	SAE limits		
5W	4·2	not less than 3·88	55	5·40
10W	5·0	,, ,, 4·20	65	6·85
20W	7·07	,, ,, 5·75	95	9·25
20	7·07	5·75–9·65	95	—
30	10·0	9·65–12·98	145	—
40	14·14	12·98–16·82	220	—
50	20·0	16·82–22·75	350	—

The extrapolated maximum limits at 0° F can be met without the need for extrapolation and without additional restriction if the viscosity in centistokes at 100° F is not more than a given multiple of the viscosity at 210° F. Appropriate multiplying factors are given in Table III. In the author's view this is a simpler method of controlling the low-temperature viscosity than the use of the ASTM charts.

There is room for improvement in the low-temperature viscosity of the SAE 10W and 20W grades, particularly the latter, and it is suggested that the limiting viscosity ratios 100°/210° F should be amended to 6·5 and 8·5, corresponding to extrapolated viscosities of 2000 and 7000 cs, respectively.

The inclusion of minimum viscosities at 0° F is not desirable, and their appearance in the classification for 10W and 20W grades is only a roundabout way of limiting the minimum viscosity at the working temperature. It is considered better to accept the waivers in the official SAE classification, which are given as footnotes to Table I.

Rationalization of the Classification

Examination of the SAE classification shows that it approximates to a logarithmic scale; this was probably not the explicit intention of the compilers of the classification, but nevertheless such a scale is highly

desirable from the practical point of view, where a unit corresponding to a given ratio of change of viscosity is more significant than a unit corresponding to a given absolute change. The viscosity at 210° F is approximately doubled for each twenty SAE numbers increase; thus an increase of ten numbers corresponds to a viscosity increase of about 41 per cent (viscosity ratio is the square root of two), and an increase of five numbers corresponds to a viscosity increase of about 19 per cent (viscosity ratio is the fourth root of two).

Table III gives a suggested rationalization on the above basis in which the modified mid-viscosities at 210° F for the 10W, 30, and 50 grades are, 5, 10, and 20 cs respectively, which are simple numbers, easy to remember. The mid-viscosities for all grades lie within the SAE prescribed limits, and the rationalization is considered to be an improvement on the SAE classification.

The proposed logarithmic SAE scale is expressed as follows :—

$$\text{SAE No.} = 66{\cdot}5 \log_{10} (\text{viscosity cs at } 210^\circ \text{ F}) - 36{\cdot}5$$

The viscosity limits for each grade should be five logarithmic numbers from the grade designation number, with the exception of 5W, for which the lower limit should be $2\frac{1}{2}$ (3·86 cs).

Although not given in the SAE classification, it is clear that there should also be upper limits to the viscosity at 210° F for the " W " grades, as otherwise the oils may be undesirably viscous. The upper limit for the 20W grade should be the same as the upper limit for the 20, and the upper limit for the 10W should be the same as the lower limit for the 20; a suitable value for the upper limit of the 5W is $2\frac{1}{2}$ log SAE number above the proposed mid-viscosity, namely 4·58 cs.

If these proposals are adopted, true double branding is possible only in the overlapping viscosities of 5W and 10W; this is not undesirable, since these two grades are relatively close together. In certain applications, however, such as those of the Armed Forces, it may be uncertain in what climate the oil will be used; it may then be necessary to combine with the running viscosity of the higher grade numbers the starting viscosity of lower grade numbers. Such composite branding is not true double branding, and these oils should be given grade numbers according to their running viscosities, even though they have reduced viscosities at starting temperatures. A suggested nomenclature is to add a second W.

Transmission and Axle Oils

The transmission and axle lubricant classification as revised by the SAE in September 1948 is given in Table IV. This can be rationalized similarly to the engine-oil classification to that given in Table V. The corresponding log SAE numbers are included so that the viscosities of transmission and axle oils may be compared with engine oils; but it is not suggested that the present grade numbers should be altered, as a distinctive system for transmission oils is useful to avoid their confusion with engine oils.

On the grounds of uniformity it is suggested that the working viscosity of all grades should be specified at 210° F. The proposed mid-viscosities at 210° F given in Table V, which have uniform 15 log SAE number intervals, provide a logical basis for the classification. As shown previously

TABLE IV

SAE Transmission and Axle Lubricant Classification

SAE Viscosity Number	Viscosity range			Consistency, must not channel in service at °F
	Control temp, °F	Saybolt Universal Sec	cs	
80	0	100,000 max	21,800 max	−20
90	100	800–1500	173–324	0
140	210	120–200	25·1–42·9	+35
250	210	200 min	42·9 min	—

TABLE V

Rationalized SAE Viscosities for Transmission Oils

SAE Viscosity No.	Logarithmic SAE No.	Viscosity at 210° F cs		Approximate Redwood No. I sec at 140° F for proposed mid-viscosity (90 V.I.)	Extrapolated viscosity at 0° F is satisfied if cs 100° F/cs 210° F is not more than
		Proposed mid-viscosity	SAE limits		
80	30	10·0	—	145	10·9
90	45	16·8	—	275	—
140	60	28·3	25·1–42·9	550	—
250	75	47·6	42·9 min	1100	—

the extrapolated viscosity at 0° F can be obtained from the ratio cs 100°/210° F; this is applicable to the 80 grade as shown in Table V.

RECOMMENDED GRADES

There is a tendency in practice to use oils which are too viscous. Viscous oils were necessary in the past in order to avoid piston scuffing and to give satisfactory control of oil consumption. Nowadays, however, Premium and HD oils contain additives which give ample lubrication even in the thinner grades, and improved piston and ring design has made it possible to obtain low oil consumptions regardless of oil viscosity.

The advantages to be gained by the use of thinner oils are very considerable, and the more important being :—

(1) easier starting;

(2) reduced mechanical losses with consequent improved fuel consumption;

(3) lower oil and bearing temperatures as a result of reduced friction, and also as a result of increased rate of oil circulation, provided, of course, that the oil pump has sufficient reserve capacity;

(4) better heat transfer so that air-cooling of the sump and oil coolers is more effective;

(5) Reduction in carbon and lacquer deposits.

Tests by the author have shown that oil temperature in engines and transmissions increases by approximately two-thirds of a degree for each

degree increase in atmospheric temperature. This, together with recent experience with oils less viscous than those normally used, has enabled recommendations (Table VI) to be prepared for well-designed gasoline and diesel engines in good condition; for old or worn engines a heavier grade may be necessary.

TABLE VI

Maximum atmospheric shade temperature	Recommended SAE Viscosity No.
50° F (10° C)	5W
68° F (20° C)	10W
104° F (40° C)	20 or 20W
Above 104° F (40° C)	30

As with engine oils, transmission oils of unnecessarily high viscosity are often used, and recommendations for hypoid and general-purpose transmission and axle oils are given in Table VII.

TABLE VII

Maximum atmospheric shade temperature	Recommended SAE Viscosity No.
68° F (20° C)	80
Above 68° F (20° C)	90

In some systems, however, it may not be practicable to use the lower-viscosity oils because of inadequate sealing; in others, oils of even lower viscosity than given above may be used with advantage.

The temperature during November to March in Great Britain and most of Europe will not rise above 68° F, so that grades 10W and 80 are appropriate winter grades of engine and axle oils respectively. Again, European summer temperatures will not exceed 104° F, and summer grades are therefore 20W or 20 and 90.

CONCLUSIONS

The following main recommendations are made :—

1. That the working viscosity of all grades of both engine and transmission oils should be specified in centistokes at 210° F;
2. That the limits for the working viscosities of engine and transmission oils should be modified slightly in line with the proposed logarithmic system;
3. That upper working viscosity limits for the " W " grades should be added;
4. That the maximum starting viscosity, where applicable, should be specified in centistokes at 0° F, obtained by specifying the maximum ratio of the viscosity at 100° F to that at 210° F;
5. That the pour point should be specified as at least 15° F (8° C)

below the lowest expected starting temperature. This, together with the extrapolated maximum starting viscosity at 0° F, is considered to be at least as effective a control of low-temperature viscosity as determined viscosities at 0° F, and is much simpler.

These recommendations are believed to provide a rational basis for the SAE classification, together with a considerable simplification. Further, oils classified according to the rationalized system normally still meet the SAE specifications, and only minor restrictions are implied.

There are considerable gains to be had from the use of the less viscous oils, and the following engine and axle oils are recommended for Europe :

Winter, 10W and 80;
Summer, 20W or 20 and 90.

ACKNOWLEDGMENT

In conclusion, the author wishes to thank the chairman of the Anglo-Iranian Oil Co. Ltd. for permission to publish this note.

CLASSIFICATION OF BITUMENS IN ASPHALT TECHNOLOGY BY CERTAIN RHEOLOGICAL PROPERTIES

PART II

THE CONCEPTION AND DERIVATION OF VISCOSITY NUMBER AND OTHER RELATED NEW INDICES

By S. L. Neppe (Member)

Summary

The general adoption in bitumen investigations of a modified form of trough viscometer to give identical readings to the BRTA orifice instrument in a more rapid and convenient manner is strongly advocated.

As a sequel to exhaustive experimentation with a very wide range of bitumens specially produced in the laboratory by diverse processes from a large variety of petroleum crude oils, the author has made a graphical study of the inter-relationships between various rheological characteristics of asphaltic bitumens. Conclusive evidence is provided that the dimensions and shape of the penetrometer needle are responsible for certain breaks in the curves relating penetration with other properties. These breaks occur at 54 pen in accordance with the writer's conception of " true penetration " outlined in Part I of this work.

Consequent upon a number of striking observations made from a critical examination of the graphs, the author has developed three new classification methods in which identical index values have been assigned to each class of perfectly normal bitumens irrespective of the system used. These are :—

(*a*) Viscosity Number—relating viscosity at any one of three temperatures with bitumen penetration at 77° F;
(*b*) Softening Point Number—relating softening point and penetration;
(*c*) Softening Point Viscosity Number—relating viscosity with softening point.

The higher the Viscosity Number (or related index) for a given penetration of bitumen, the lower is the susceptibility to temperature change.

The rationality of the Viscosity Number chart is clearly demonstrated by the fact that a true linear relationship exists for all values of log log viscosity plotted against log absolute temperature.

Moreover, in a single chart co-ordinating Viscosity Number and Softening Point Number data, the author shows that for a given series of perfectly normal bitumens of fixed Viscosity Number, all the softening points lie in one and the same straight line. The theoretical viscosities at softening point temperatures noted from this diagram and ranging from 6000 to 40,000 poises agree very well with previously recorded figures. Equations are presented for different classes of bitumen relating viscosities in poises with softening points.

EXPERIMENTAL WORK FOR THE STUDY OF RHEOLOGICAL PROPERTIES

Selection of Samples

The need for a proper and careful selection of suitable basic samples in work of this nature cannot be over-emphasized. Far too many conclusions reported in the past by various investigators have been misleading simply

because of the lack of sufficient truly representative samples. Unless some systematic scheme is followed, samples selected at random may be misleading and may fail to disclose information necessary for a clear-cut interpretation of experimental data.

Owing to the limited varieties of bitumens produced or imported into South Africa during the war years, it was evident in the early stages of these investigations that it would be extremely difficult to procure a complete and satisfactory range of samples likely to be encountered in practice under all sorts of conditions. Particular difficulty was experienced in obtaining even a limited number of samples of different penetrations from the same suppliers, and then no guarantee could be given that the materials were representative of a given series produced from the same raw materials by the same system of refining. In no case too was the history of the bitumen known.

The writer therefore had no alternative but to prepare all the necessary bitumen samples himself. Fortunately, during his association with the South African Torbanite Mining and Refining Co. Ltd., he had access to a number of samples of different asphaltic crude oils from different parts of the world and containing various percentages and types of natural straight-run bitumen.

It was therefore decided to process selected diverse types of oils in the laboratory under carefully controlled conditions so as to obtain a sufficient range of varieties from highly cracked to air-blown natural bitumens.

In all, materials from fifteen different sources were used during the exploratory stages of the investigation. By suitable treatment, however, twenty-six different series were finally obtained, the same basic soft material being generally subjected, where convenient, to air-blowing as well as steam refining (or vacuum distillation). During the preparation of each series, a number of samples of different degrees of hardness were drawn off at convenient intervals, so that in general each series was fully represented by samples ranging from over 200 pen down to about 10 pen in many cases. In several instances more than twenty samples were prepared for a single series. The total number of samples at this stage was 274.

A key to the various series of samples is given in Table IV. Each series has been assigned an identification letter, and each member of any series has been allocated an additional number following the parent letter, the numbers being arranged in sequence in order of the hardness.

Owing to lack of knowledge of the specific characteristics of each class at the outset of this investigation, it was obviously impossible to decide on any fixed order of nomenclature at that time. For convenience of the present discussions, however, the letters as given in the table have been rearranged to follow a definite plan based on the author's proposed schemes of classification—see later—in which Series A indicates a class at one extreme and Z a class at the other. It is also worth pointing out at this stage that the range of samples covered by the present study has been found to be most comprehensive and includes practically all classes normally encountered in highway engineering.

No useful purpose can be served here by describing the actual source of each material. This would lead only to undesirable controversy, and for this reason no bitumen will be identified in the present work by its geo-

TABLE IV

Key to Series of Samples Investigated

Series	Method of preparation	Type of bitumen	Bitumen Group No.
A	Air blown	Severely cracked	1
B	Steam refined	Severely cracked	2
C	Air blown	Severely cracked	3
D	Steam refined	Cracked	4
E	Air blown	Severely cracked	2
F	Air blown	Severely cracked	5
G	Air blown	Cracked	6
H	Air blown	Cracked	4
I	Vacuum distilled	Slightly cracked	7
J	Steam refined	Natural	8
K	Air blown	Slightly cracked	7
L	Air blown	Natural	8
M	Steam refined	Slightly cracked	9
N	Air blown	Slightly cracked	9
O	Steam refined	Natural	10
P	Steam refined	Natural	11
Q	Steam refined	Natural	12
R	Steam refined	Natural	13
S	Air blown	Natural	12
T	Steam refined	Natural	14
U	Air blown	Natural	14
V	Air blown	Natural	13
W	Air blown	Natural	10
X	Air blown	Natural	11
Y	Steam refined	Natural	15
Z	Air blown	Natural	15

graphical or commercial origin. Each material can then be examined on its merits alone and not on the basis of preconceived ideas. On this point the views of Lee, Warren, and Waters [4] may be cited :—

> " The scientific description of naturally occurring products frequently presents some measure of difficulty. Obviously no one would regard ' British coal ' as a clear scientific description. Similarly, it is inaccurate and misleading to refer to ' Californian bitumen,' since several types of crude oils occur in the large area of California. On the other hand, a fuller description associating any particular oil with the well from which it was obtained at a particular date would not be any more helpful, since such a description would only be imperfectly understood even locally. In the circumstances the best that can be done is to refer to the products under consideration as ' a type of Californian bitumen,' etc., and to rely upon the chemical data to supplement the description."

Preparation of Samples

The severely cracked series were mostly obtained direct from a large-scale high-pressure–high-temperature cracking unit in which recycle distillate oils such as kerosine and gas oil were being treated primarily to form gasoline, the cracking-coil tar being a by-product of the reaction. In some cases the cracked products were specially prepared in a laboratory autoclave, under suitable cracking conditions. This apparatus has been described elsewhere by the writer.[2, 3]

The slightly cracked samples were so named because they were blends of the natural straight-run bitumen originally present in a certain petroleum crude oil with the bitumen resulting from the cracking of its associated oil

fractions. The characteristics of the final resultant bitumen in each case were a function of the relative proportions and properties of the constituent fractions.

Complete ranges of samples were prepared for each broad class of materials indicated in Table IV under Series A to Z. Penetrations in general ranged from about 200 down to about 10. As mentioned earlier, three methods were utilized in the laboratory for the preparation of the samples : (i) steam refining; (ii) vacuum distillation; (iii) air blowing.

The first two methods are very closely related, both being dependent on the removal of oil vapours under reduced pressure, and therefore at lower operating temperatures than can be achieved at atmospheric pressures. The adoption of these methods was necessary to avoid alterations in the natural characteristics of the materials by decomposition at elevated temperatures. In general, the temperatures used ranged from 500° to 550° F for the preparation of the softer grades of bitumen and from 550° to 600° F for the harder samples.

In some instances the original crude oils contained an appreciable amount of water, usually in the form of an emulsion which could not be removed by straight distillation owing to abnormal bumping and boiling over. Such difficulties were usually overcome by blowing a stream of nitrogen through the oil during the distillation process until dehydration was complete.

About 1 gal of liquid or soft residue from which the light oils had previously been topped off by straight atmospheric distillation was used for each steam or vacuum treatment. The apparatus consisted of a specially constructed iron still fitted with a run-off valve through which samples as indicated above were drawn off periodically.

In most instances several distillations were necessary to give sufficient material for all the subsequent tests, this object being achieved also by judicious blending of various members of the same bitumen series but of different penetrations. At least a pint of each sample was prepared.

The sample tins all had closely fitting lids, and all samples, when not in use, were stored in the dark. Negligible changes in the physical characteristics of the materials were discernible even after storage for four years, which was the maximum period over which any sample was retained for testing purposes.

Air-blown Samples.—It is a known fact that some classes of material are far more susceptible to changes in their characteristics by air-blowing than others. For this reason the various series of air-blown bitumens were all prepared in the same laboratory equipment under similar controlled conditions so that their relative susceptibilities to air-blowing could be directly compared.

The compressed air was initially freed of entrained oil and dust by passage through a muck trap. It was then passed through a calibrated laboratory flow meter at 35 cu. ft/hr (measured at 80° F and 630 mm of mercury) into a special contactor, where it was saturated with water vapour at 80° F. An empty 2-litre flask in which saturation equilibrium could be reached was connected in series with the contactor. The air was then passed through a pre-heater coil submerged in hot oil at 280° to 300° F, in order to ensure that no water entered the still in the liquid state. The superheated

air, fed in a constant stream of uniform quality, was finally blown through an umbrella spray into the bituminous residue in the still, which was maintained at a temperature of 450° F throughout the blowing operation. The mixture of air and vapour leaving the still passed into a 3-litre flask from which the gases were exhausted to the atmosphere.

Rheological Tests Studied in the Present Investigation

In order to obtain consistency and viscosity data over an extended range of temperatures, the importance of which has already been discussed,[1] the following groups of tests were carried out :—

(*a*) penetrations at different temperatures ranging from 77° down to 38° F, with particular reference to results at 77° F;

(*b*) ring and ball softening points;

(*c*) viscosities in BRTA seconds at three standardized temperatures, viz., 140° F (60° C), 158° F (70° C), and 176° F (80° C);

(*d*) Redwood No. II viscosities at different temperatures ranging from 212° to 302° F, with particular reference to results at 275° F;

(*e*) ductilities at different temperatures ranging from 77° down to 37·5° F.

The temperature ranges thus covered included cold conditions, the normal atmospheric service range, the high road temperature or intermediate range, and the mixing temperature.

The penetration, softening point, and ductility tests have already been fully discussed by the author in Part I of this work.[1]

The measurement of BRTA viscosity will be dealt with separately in the next section.

All Redwood viscosities have been converted to the equivalent Saybolt values by means of recognized tables, in order to facilitate examination of the HCC Fluidity Index and Zapata Fluidity Factor.

The results of the various rheological tests for all the samples under review have been recorded under the relevant headings in a series of tables too voluminous to publish here, but are clearly depicted in a number of graphs which will be referred to as required in the discussions following. The present paper is confined to penetration tests at 77° F and to items (*b*) and (*c*), while Parts IV and V will deal fully with items (*a*), (*d*), and (*e*).

Use of Selvey's Modification of the Metro Trough Viscometer for the Determination of BRTA Viscosities

At the outset of the present work it was realized that it would be necessary to carry out a considerable number of viscosity determinations at several different temperatures. The urgency for a convenient, simple, and rapid instrument to replace the cumbersome standard BRTA viscometer soon became apparent as the latter apparatus, fitted with a 10-mm diameter orifice, had been designed on the Redwood principle—for testing tars, usually at low temperatures of 86° and 95° F. Various considerations of the problem were necessary.

The first requirement of a suitable viscometer is ability to ensure uniformity of temperature within about 0·2° F throughout the sample under test. At viscosities exceeding about 125 sec it is, however, most difficult to

achieve this by any ordinary means with the BRTA viscometer, primarily because of the extremely small capacity of the water-bath in relation to the fairly large quantity of sample employed. This point is most important, since the test procedure specifies a constant time factor of 1 hr before the material is allowed to flow through the orifice. In addition, the upper surface of the tar and the bottom of the viscometer cup are exposed to the atmosphere, so that temperature control is most uncertain, particularly with viscous bitumens at high temperatures ranging from 140° to 176° F.

Another most important consideration that had to be taken into account in these investigations was the relatively small quantity of material which could be spared in most cases for viscosity testing.

In order to overcome the disadvantages of the BRTA viscometer, in addition to the reasons given below, the writer decided to use Selvey's modification [5] based on the Metro Trough viscometer described by Evans [6] and Pickard.[7]

This instrument has the advantage that the same sample can be tested a number of times at different temperatures. Another attractive feature is that the total immersion of the viscometer in the water-bath assists in shortening the time required to adjust the temperature of the sample accurately to any desired point, particularly since the bath capacity may be unlimited.

In view of the important part played by the modified trough viscometer in the present work, and since the writer unhesitatingly advocates the more general adoption of this instrument as a recognized standard for the measurement of bitumen viscosities, a fairly full description is given below, mainly in Selvey's own words.

The arrangement is depicted in Fig 9. The principle involved is measurement of time of flow of a liquid down an inclined channel. The viscometer itself consists of a 4½-inch length of ¾-inch-bore thin-walled brass tubing, preferably nickel-plated, sealed at one end for use as the receptacle for the material, the viscosity of which is to be measured. The capacity of the instrument is approximately one-tenth of that of the standard BRTA viscometer, being about 11 ml as against 113 ml.

> "The centre portion of the tube is cut away to form a semi-cylindrical trough on the inside surface of which two lines are engraved. The other end of the tube is left open to facilitate cleaning. The trough is then enclosed in a pyrex test tube (1 inch dia by 6 inches long) sealed with a rubber stopper through which passes a short length of fine capillary tubing to release any air pressure at high temperatures."

The present investigator, however, found that, with Selvey's design, water is sucked into the tube through the capillary when the temperature is lowered. Consequently, he has incorporated a further modification by inserting a short length of glass tubing through the rubber stopper, as shown in Fig 9, so that the open end is always above the water surface irrespective of the position.

> "The test tube and its enclosed trough is held in a brass carrier by means of a rubber band. Near one end of its under-surface is soldered a 'U'-shaped piece of flat brass to form a bearing; at the other end an adjustable screw serves as a rest for the instrument, when in the inclined position, and determines the angle of the incline. Fastened at either end of the upper surface of the carrier are two semi-circular pieces of brass rod which serve as a rest for the test tube. The holder is further fitted with a long brass rod pivoted at one end, and bent to

form a double hook at the other. By engaging the top hook with the side of the water bath, the viscometer can be kept in a nearly vertical position while temperature adjustments are made. The bottom hook engages with the opposite side of the bath when the viscometer occupies the inclined position. The brass rod also serves as a handle for moving the viscometer from the vertical to the inclined position and for removing and replacing it in the water bath. The water bath is provided with a stand having levelling screws and incorporating a straight gas stove burner for rapid heating. A suitable fitting is provided for the thermometer which is graduated in tenths of a degree Celsius. A bottle brush, to which is soldered a hook to suspend it from the edge of the bath when not in use, makes an excellent stirrer."

Viscosity determinations are made by tilting the trough at a small angle (about 10 degrees) to the horizontal, and measuring the time required

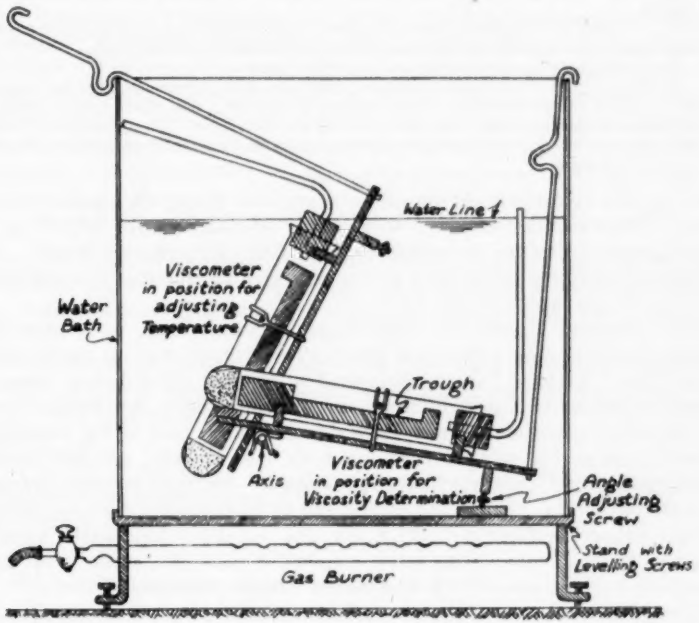


FIG 9

SELVEY'S MODIFICATION OF METRO-TROUGH VISCOMETER

for the material under test to cover the distance between the two engraved lines. The time taken to flow from the receptacle and to reach the upper line is not taken into account.

Several tests can be carried out simultaneously in a series of instruments in the same water-bath,

" which is fitted inside with a brass rod running the full width of the bath, parallel to the bottom and one of the sides. This rod acts as a common axis on which are pivoted a number of trough viscometers. A length of inch by eighth flat brass is soldered to the bottom of the bath in a position exactly parallel to the axis, and so placed as to form a rigid support for the end of the viscometers when in the inclined position."

In the present work the bath was made to accommodate six viscometers.

> "The time required to make a viscosity estimation is mostly consumed by waiting for the tar to attain a uniform temperature equal to that recorded by the water bath; the advantage of having several viscometers in the same water bath is therefore clear."

Other advantages claimed by Selvey for his modification as against the Metro Trough viscometer are :—

> "1. The use of a standard size pyrex test tube eliminates breakage of the glass container excepting by accident, and facilitates its replacement.
> 2. Easy and complete visibility of trough.
> 3. The viscometer can be removed and replaced in the water bath without interfering with the level or wetting the fingers.
> 4. Removal and replacement of the trough in its glass container is rapid and simple.
> 5. The use of a rubber stopper is a better and simpler means of making a water-tight seal than a screw cap and exerts much less strain on the glass.
> 6. The trough may be easily and rapidly cleaned.
> 7. The cup of the trough viscometer requires filling once only for any number of viscosity measurements. After timing a viscosity, the viscometer is removed from the water bath and the trough from its test-tube. The trough is warmed, and the tar, which has run out of the cup, returned thereto by one stroke of a small rubber squeegee."

Selvey has demonstrated by actual tests that under all possible experimental conditions a period of 15 minutes is sufficient for adjusting the temperature of the tar to within 0·1° F of the surrounding water. The present investigator found that a time factor of 20 minutes was preferable for his work on asphaltic bitumens.

Since physical properties other than viscosity, such as density and surface tension, may affect the flow differently in various instruments, Evans [6] and Pickard [7] have examined a number of different tars and asphaltic bitumens under different conditions in both the Metro Trough and BRTA viscometers. They have demonstrated that if log viscosity is plotted against log temperature for both instruments, parallel straight lines are obtained, showing that the results can be fairly closely correlated by a simple factor. Since the same type of relationship does not exist in certain other instruments which do not measure kinematic viscosity directly, these investigators have concluded that the same property is measured by both the BRTA and Metro Trough viscometers.

Selvey has made use of the above facts and has adapted his modification to give direct readings in agreement with those of the BRTA viscometer, simply by careful adjustment of the levelling screw at the bottom of the trough carrier. It should be noted that one very great advantage of Selvey's method is that, for a series of home-made viscometers varying fractionally in size or in the exact positions of the engraved lines, each instrument can be standardized independently of the others by means of its own setting screw, so that identical results are obtainable in all cases. That is, the angle of inclination is not critical and can be varied according to circumstances.

The above procedure has also been adopted by the present worker, who has calibrated his viscometers by tests on a series of different quality bitumens at a number of temperatures. The interesting fact has been established that the trough viscometer gives far more consistent viscosity values above 125 sec than the BRTA instrument. The reasons for this

have already been indicated. It has been found that results even greater than 1000 sec are reproducible with a high degree of accuracy.

All viscosities determined with the trough viscometer have accordingly been recorded directly as BRTA seconds throughout the present investigations, although, strictly speaking, high viscosity values are beyond the range of the standard BRTA instrument.

Wherever necessary, the BRTA values have been converted to kinematic viscosities in centistokes simply by multiplying BRTA seconds by 394. The latter conversion factor has been established by Pickard [7] and, according to a private communication received by the present author, is recognized as the standard by the British Road Tar Association. BSS No. 76, however, gives a factor of 400.

This investigator's preference for Selvey's trough viscometer as against the standard BRTA instrument is, in fact, a confirmation of the conclusions of Pickard. The latter has demonstrated that the mean deviation from the average correlating factor between the Metro Trough viscometer and an absolute rotating cylinder apparatus is 1·0 per cent, with a maximum deviation of 1·5 per cent, whilst the corresponding deviation for the BRTA viscometer is as much as 4·0 per cent, with a maximum of 8·0 per cent.

Graphical Representation of Experimental Results

The experimental results obtained for Series A–Z are illustrated graphically in Figs 10, 11, and 12 respectively, each diagram relating two of the three fundamental properties of viscosity, penetration, and softening point.

The methods of plotting adopted in this work follow the principles discussed in Part I with regard to the necessity of logarithmic representation of rheological data. Thus :—

Fig 10 shows—

> Log viscosity (in BRTA seconds) *vs* log penetration at 77° F in three distinct constant temperature bands, one each for 140° F, 158° F, and 176° F in succession.

Fig 11 shows—

> Log softening point *vs* log penetration at 77° F.

Fig 12 shows—

> Log viscosity (in BRTA seconds) *vs* log softening point. In this case, too, three distinct isothermal bands are shown corresponding to Fig 10.

The following observations are apparent from the three sets of curves :—

1. In general, straight-line relationships exist, within limits, between any two of the three properties as plotted in the diagrams. The degree of divergence from this rule is small. The writer has consequently, for the sake of clarity, omitted from the graphs the considerable number of individual points pertaining to each of the various series of samples. Inclusion of the relevant points in these diagrams would lead only to unnecessary confusion owing to the difficulty of differentiation between the various series.

2. Marked changes in the slopes of the lines are noticeable for the curves involving log penetration, particularly in the region of 54 pen at 77° F

(see Figs 10 and 11). This is a direct consequence, as discussed in Part I, of the physics involved in the penetration test itself, and arises as a result of the tapered shape of the tip of the standard ASTM penetrometer needle.

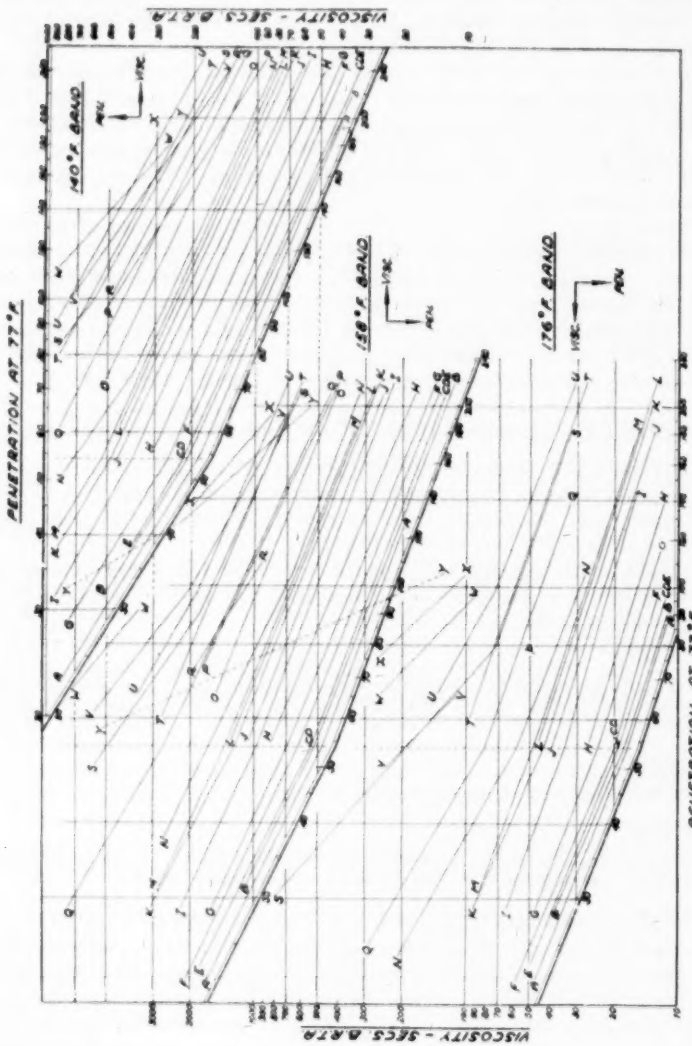


Fig 10

EXPERIMENTAL DATA RELATING BETA VISCOSITIES AT THREE TEMPERATURES WITH PENETRATION AT 77° F.

3. It is particularly significant that no sharp breaks occur at the appropriate points in the corresponding lines obtained for the same series of samples by plotting log viscosity at the three specified temperatures against log softening point (Fig 12). Since the penetration factor is not under

consideration in this diagram, it follows conclusively that the breaks at about 54 pen in the curves of Figs 10 and 11 are due to the dimensions and shape of the penetrometer needle.

4. Sharp breaks also occur in the case of several other samples at points corresponding to penetration above 54 at 77° F. This applies to Fig 12 as well as to Figs 10 and 11. This phenomenon is attributed to changes

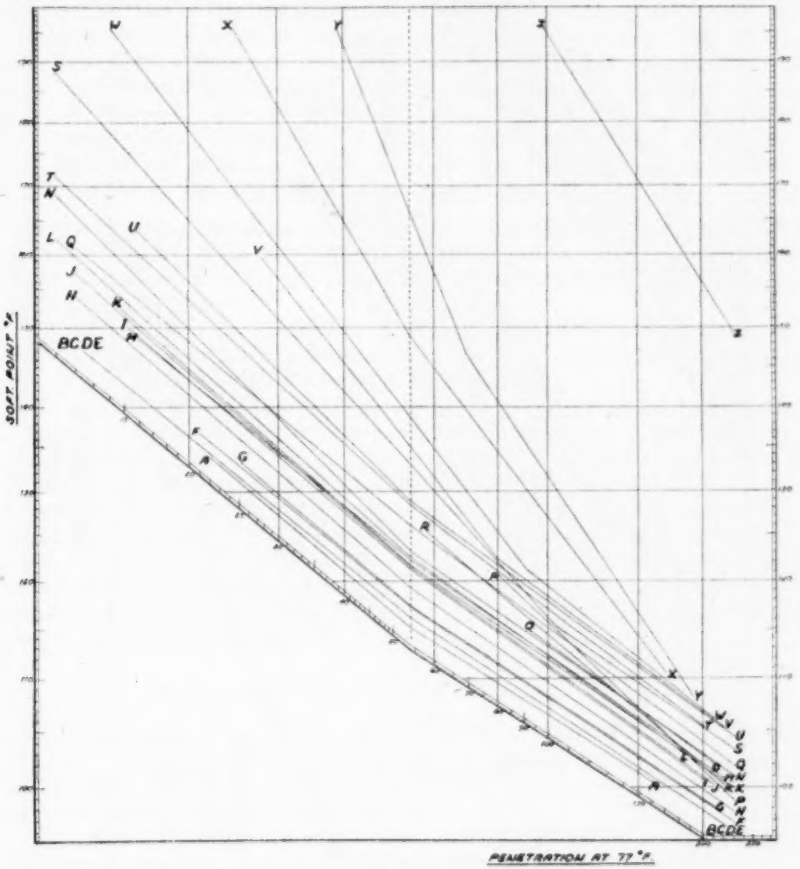


Fig 11

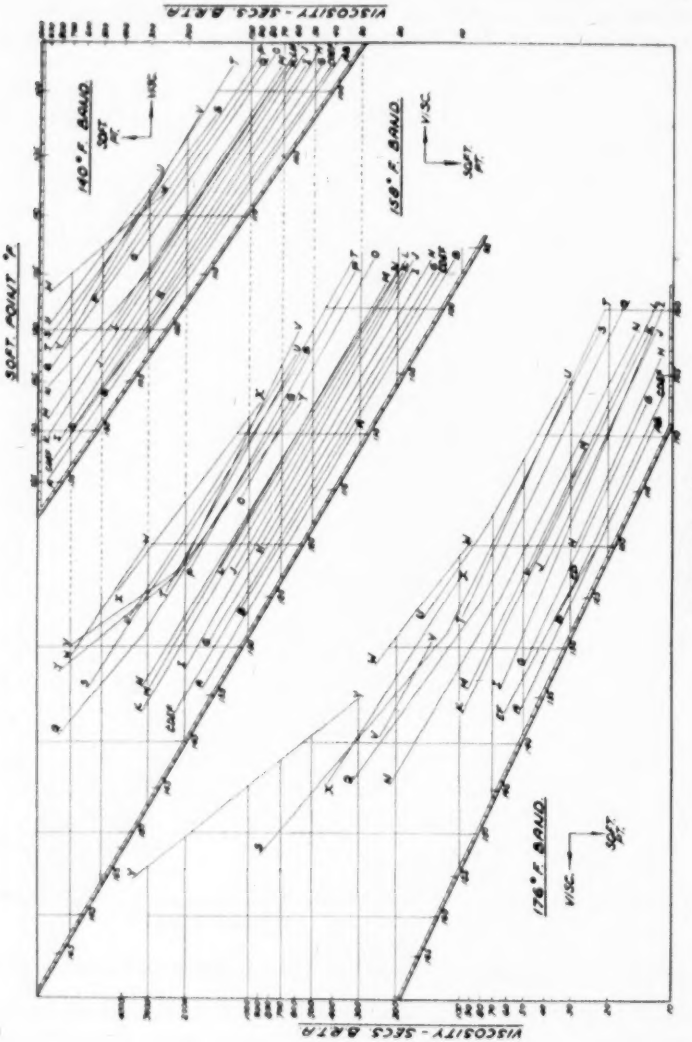
EXPERIMENTAL DATA RELATING R AND B SOFTENING POINT WITH PENETRATION AT 77° F

in the physical conditions of the materials arising from the manifestation of anomalous flow properties, such as plasticity, etc., under the particular temperature and other conditions of the various tests.

The sharp change in the slope of a line at any point may thus be due to either or both of two major, but entirely independent causes viz. :—

(*a*) dimensions of penetrometer needle;
(*b*) anomalous flow properties.

The first cause has a constant effect on the magnitude of the slope but the second is a variable. The resultant slope is therefore a function of the relative effects of the two components.



EXPERIMENTAL DATA RELATING BRTA VISCOSITIES AT THREE TEMPERATURES WITH R AND B SOFTENING POINTS

FIG 12

5. A comparison of the slopes of the curves for each of the three diagrams shows the following important facts :—

(*a*) The various curves in each constant temperature band of Fig 10 are substantially parallel to each other, particularly for penetrations

above 54 at 77° F. In addition, the average slope of the lines (for penetrations at 77° F higher than 54) is lower for the 176° F band than for the 158° F, which in its turn is lower again than for the 140° F. In fact, there appears to be a constant " angle of rotation " from band to band.

(*b*) In the case of Fig 11, for penetrations above 54, the lines are not parallel, there being a general tendency for a gradual increase in slope with increase in softening point for a given penetration. In this case too there is a constant angle of rotation from line to line.

(*c*) Since Figs 10 and 11 are plots of viscosity *vs.* penetration, and of softening point *vs* penetration respectively, it follows that the general trend of the lines in Fig 12—in which viscosity is plotted against the softening point—must be due to a resultant slope influenced by the respective lines in Figs 10 and 11.

6. In general, the position of the various curves with respect to each other and the order in which they occur are essentially the same for each of the three diagrams, including the three distinct constant-temperature bands in each of Figs 10 and 12.

In addition, for Fig 10, the width of each of the three bands, between any two given series, when measured for the same abscissa limits (above 54 pen), is approximately the same in each diagram.

7. It is clear that the series of samples covered by the present work are reasonably representative of all possible series ranging in properties from those of Series A, B, and C at one extreme to Series W, X, and Y at the other. The viscosities of the members of Series Z were found to be so high, when related to their respective penetrations at 77° F, that it was inconvenient to plot the lines for this series in Figs 10 and 12 on the same scale as that used for the others. An indication of the correct position of the lines for Series Z relative to the others can be gauged from Fig 11, in which the gap between Series Y and Z is actually wider than the total width of the band embracing all the other series from A to W on the same diagram.

Derivation of the Viscosity Number Chart

The foregoing observations were so striking that the writer decided to carry the investigations further to determine whether any regular relationships could be established between the various curves to act as a basis for a new method of bitumen characterization.

The term " Viscosity Number " was conceived as an arbitrary value to indicate the quality of asphaltic bitumen of any given penetration at 77° F according to its viscosity characteristics measured in BRTA seconds (or converted to absolute units) at any one or more of three specified test temperatures, viz., 140°, 156°, or 176° F respectively.

The fundamental assumption was made that bitumens could be classified by the positions they occupied on a specially constructed Viscosity Number chart (see later : Fig 14) having exactly the same axes and scales as Fig 10.

Thus, the higher the viscosity at any temperature in relation to penetration at 77° F, the higher would be the Viscosity Number of the bitumen.

As a starting point for the construction of such a chart, a " perfectly normal " bitumen series was defined arbitrarily as one which had the

average slope of most of the series in any particular isothermal band of Fig 10. In order not to complicate matters by the introduction of too many variables at one time, only those portions of the curves relating to penetrations above 54 at 77° F for the " normal " series were considered in the first instance. Another reason for this step was that, if the final relationship were based on " perfectly normal " bitumens alone, " abnormal " bitumens exhibiting anomalous flow, for example, would then be more easily detectable.

The problem at this stage was to devise a suitable classification chart based on the observations already made :—

(*a*) By inspection of the various normal curves in Fig 10, it was first of all necessary to determine the most representative average slopes of the lines in each band, due consideration being paid to obtaining a constant angle of rotation from band to band.

(*b*) The second step was to decide on the most suitable position of the base-line for each band to which a " Viscosity Number " of zero could arbitrarily be allocated.

(*c*) As a consequence of observation (6) above, it was decided to draw a perpendicular to each of the three zero base lines and to mark off arbitrary conveniently chosen equal intercepts for all three bands, to which regularly increasing Viscosity Numbers could be allocated. This was to ensure that the width of all bands would be identical between any two given Viscosity Numbers.

Thus, the members of Series A, comprising the most severely cracked bitumens and possessing low viscosities at 140° to 176° F corresponding to given penetrations at 77° F, were arbitrarily assigned Viscosity Numbers slightly higher than zero for all three constant-temperature bands. On the other hand, the members of Series Q, prepared by steam refining the natural bitumen present in a high-class petroleum oil and having fairly high viscosities at 140° to 176° F corresponding to the same penetrations at 77° F as for Series A, were given arbitrary Viscosity Numbers in the region of 9 to 10.

It should be realized that the final decisions as to the optimum positions of the Viscosity Number lines to conform to requirements (*a*), (*b*), and (*c*) above could be made only after numerous trial-and-error attempts, for each of which the relevant Viscosity Numbers had to be recorded in derivative tables similar to those depicting the original experimental data for all the series under consideration. This extremely tedious but most necessary process has resulted in the most suitable possible combinations under the circumstances, and has given the minimum overall deviations from the mean for any given series. The main requisite, uppermost in the mind of the writer throughout this work, has been to utilize his experimental data as a whole to the best advantage to obtain graphical relationships for all " normal " bitumens, which would follow as closely as possible some definite mathematical principles and therefore also physical laws. Deviations from the normal would thus become more easily recognizable than if the chart were constructed in a more or less haphazard manner only to suit some of the samples.

On this basis, different penetration grades of the same group or series of

"normal" bitumens have identical Viscosity Numbers at the three specified test temperatures. This, however, does not apply if the temperature of test is such that the bitumen is in a plastic or semi-plastic state, in which case the Viscosity Number is higher than normal, depending upon the actual degree of plasticity.

The next step in the derivation of the chart was to determine how to change the basic slope of each band so as to correct only for the effect of the

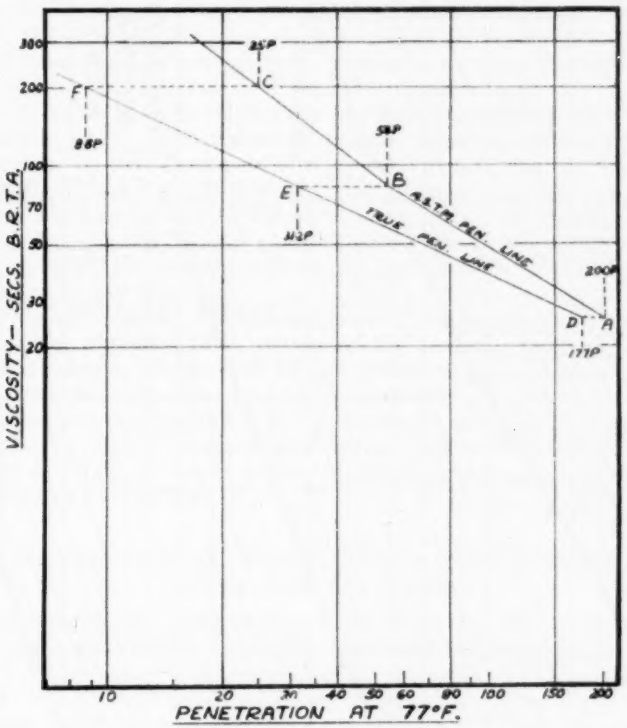


FIG 13

DERIVATION OF TYPICAL VISCOSITY NUMBER LINE FOR ASTM PENETRATIONS AT 77° LOWER THAN 54

dimensions of the penetrometer needle (*i.e.*, below 54 pen). Normal and abnormal rheological behaviours would thus immediately be evident.

At this stage it is necessary to point out that the graphical method adopted in plotting involved the logarithm of the standard ASTM or IP penetration and not log true penetration as proposed in Part I. The reason for this action was primarily to evolve a chart based on current practice which would have more universal immediate application. Had all the experimental data been plotted to a scale involving log true penetration, no break would obviously have occurred (in either of Figs 10 or 11) for normal bitumens at the point corresponding to 54 pen at 77° F on the log

ASTM penetration scale. Breaks due to anomalous flow properties are, of course, excluded in this connexion.

Reference to Fig 3 (Part I) shows that in practice log ASTM penetration

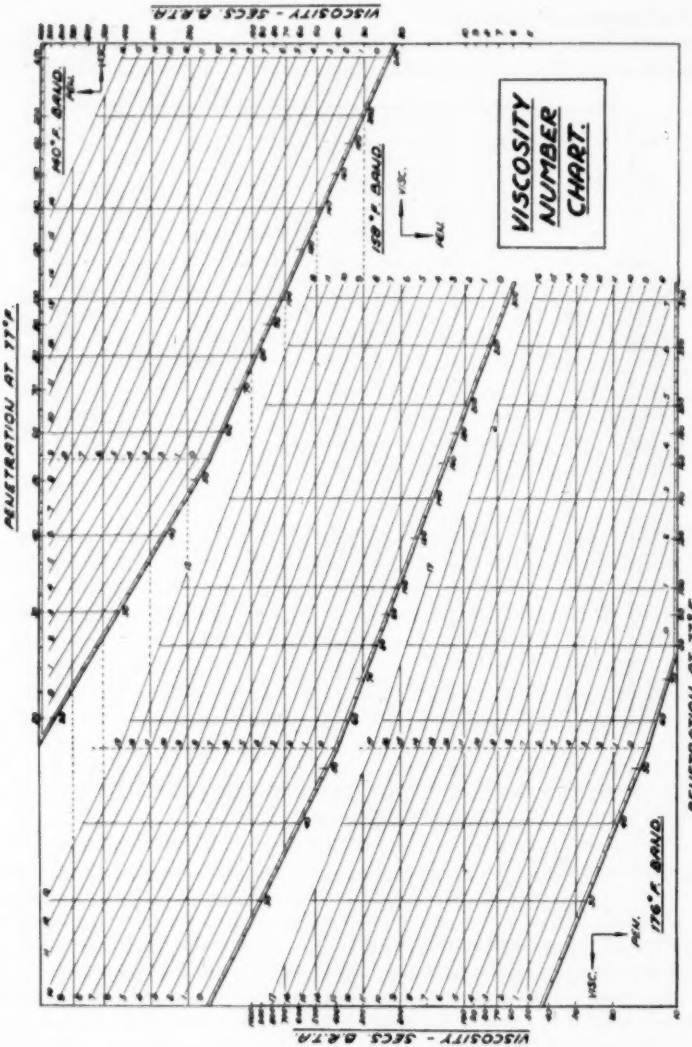


Fig 14

is reasonably directly proportional to log true penetration between ASTM penetration limits of 54 and 300 respectively. Again, that portion of the log ASTM penetration curve between 20 and 54 pen is also directly proportional to the corresponding log true penetration curve.

The slopes of the lines in Fig 10 for " normal " bitumens in respect of penetration values lower than 54 were accordingly obtained from the relationships existing between true and ASTM penetrations as indicated by Fig 3.

The general procedure adopted is illustrated in Fig 13.

Let *AB* represent the slope and position of any basic log viscosity-log ASTM penetration line in Fig 10, the point *B* corresponding to an ASTM penetration at 77° F of 54 and point *A* to 200 pen.

Plot *DE* to represent the equivalent log viscosity–log true penetration curve. For example, the same viscosity should correspond to 200 ASTM and 177 true penetration respectively; similarly, the same viscosity applies to ASTM and true penetrations of 54 and 31·2 respectively.

Extend *DE* to *F*. Obviously, if a log true penetration scale had been adopted for plotting the experimental data instead of log ASTM penetration, line *DEF* would have been part of a typical Viscosity Number line in the final chart. Point *F* (or in fact any other point on line *EF*) has a corresponding point on the log ASTM penetration scale. For example, if the abscissa of point *F* is log true penetration 8·8, the corresponding point *C* on the log ASTM penetration scale has an abscissa of 25 for the same value of the log viscosity ordinate.

Join points *B* and *C*, and the extension of the resultant line *BC* must consequently represent that portion of the original Viscosity Number line which refers to bitumens of ASTM penetration lower than 54 at 77° F.

The final Viscosity Number chart incorporating the various features indicated above is shown in Fig 14. A discussion on its merits, particularly in relation to other established methods of bitumen classification and its application to experimental results in the present work, is given more appropriately later in Part III.

The Applicability of the Viscosity Number Chart to the Viscosity–Temperature Relationship

Apart from the foregoing requirements, which influenced the positions of the various lines finally chosen to indicate the complete series of Viscosity Numbers, there was one crucial test which the chart had to pass before it could be accepted with any confidence, irrespective of its value in other directions. The question which needed an affirmative answer was: " Do the points on the Viscosity Number Chart conform to a straight-line relationship if log log viscosity is plotted against log absolute temperature, as discussed in Part I ? "

A table (not shown here) was accordingly drawn up from Fig 14, the relevant viscosities at 140°, 158°, and 176° F corresponding to ASTM penetrations at 77° F of 200, 100, 60, 40, 30, and 20 respectively being taken directly from the three isothermal bands. Four typical cases were selected in each instance, namely for Viscosity Numbers of 0, 5, 10, and 14 respectively. The derived data were then used for the construction of Fig 15, the ordinate being a log log viscosity relationship depicting BRTA seconds and the abscissa log temperature (in ° F absolute).

In all cases the curves were found to be reasonably linear. This means that the Viscosity Number chart is at least rational in basis. It should be

pointed out that this test was applied to Fig 14 only after the writer had satisfied himself that the Viscosity Number lines chosen were the optimum from the other aspects already discussed.

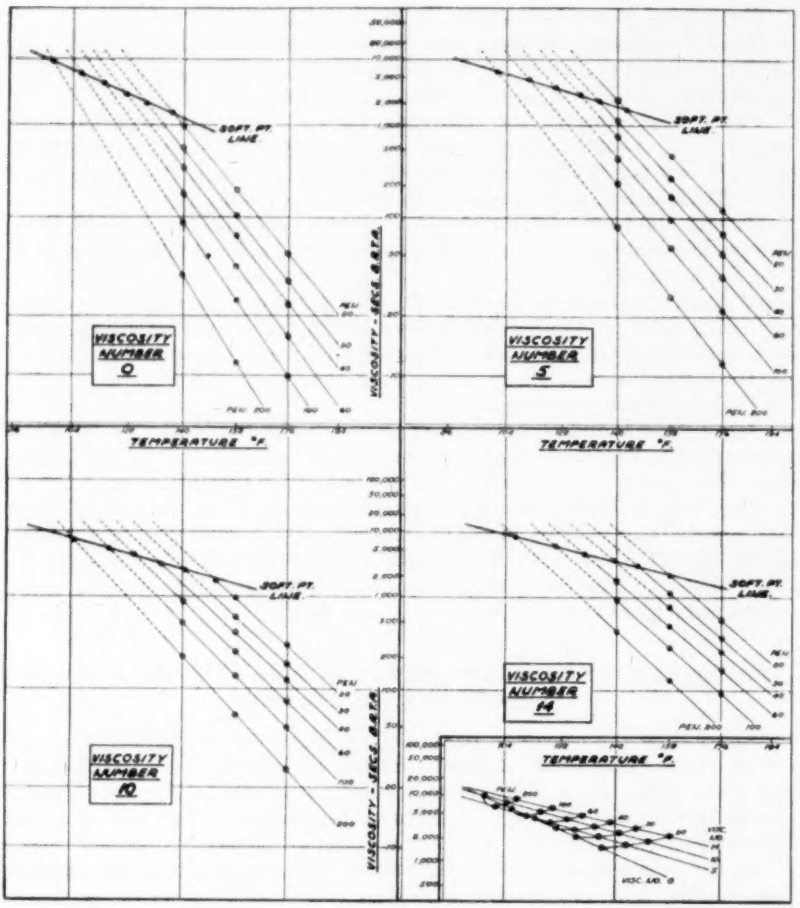


FIG 15

THEORETICAL RELATIONS BETWEEN LOG LOG VISCOSITY AND LOG ABSOLUTE TEMPERATURE FOR NORMAL BITUMENS, INCLUDING VISCOSITIES AT THE SOFTENING POINT TEMPERATURES

The negative slope of each curve is obviously a measure of the viscosity–temperature susceptibility. Thus,

$$\text{Susceptibility} = \frac{\text{Log log viscosity at } t_1 \text{ ° F} - \text{Log log viscosity at } t_2 \text{ ° F}}{\log (t_2 + 460) - \log (t_1 + 460)}$$

This relationship has been used for calculating the susceptibilities of

"perfectly normal" bitumens from the data used for plotting Fig 15. Fig 16 has then been constructed with Viscosity–Temperature Susceptibility as the vertical axis and Log True Penetration as the horizontal. The equivalent ASTM Penetrations have also been indicated for reference purposes.

The following most interesting general observations regarding the conception of Viscosity Number are clarified by this diagram :—

(*a*) The higher the Viscosity Number for a given penetration of bitumen, the lower is the susceptibility to temperature change.

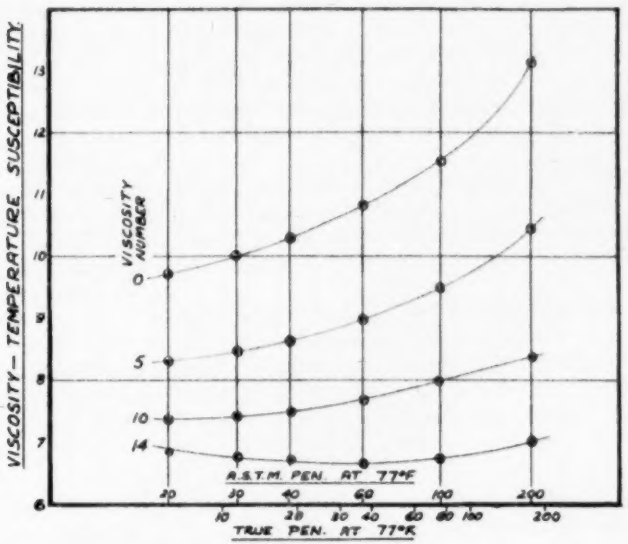


FIG 16

EFFECT OF VISCOSITY NUMBER ON THE VARIATION OF TEMPERATURE SUSCEPTIBILITY WITH BITUMEN PENETRATION AT 77° F

(*b*) For a given series of constant Viscosity Number, the higher the penetration, the higher is the temperature susceptibility (Exceptions : the harder bitumens of very high Viscosity Number (*e.g.*, V.N. = 14)—but see observation (*c*)).

(*c*) The higher the Viscosity Number, the less is the tendency for the susceptibility to vary with changes in bitumen penetration at 77° F.

These findings are most important and are typical of the viscosity characteristics of the respective normal bitumen series studied in these investigations and illustrated graphically in Fig 10. They further strengthen the validity of the "Viscosity Number" chart.

The curves in Fig 15 have also been used for determining the theoretical viscosities of perfectly normal bitumens at their respective softening points, but this aspect must be deferred for the moment until the "Softening Point Number" chart has been discussed.

Derivation of the Softening Point Number Chart

As a sequel to observations 5 and 6 discussed earlier, it was felt that his Viscosity Number might also be closely related to Softening Point Number. The next problem then was to produce a chart (see Fig 17) based on the experimental results used for the construction of Fig 11 and having the

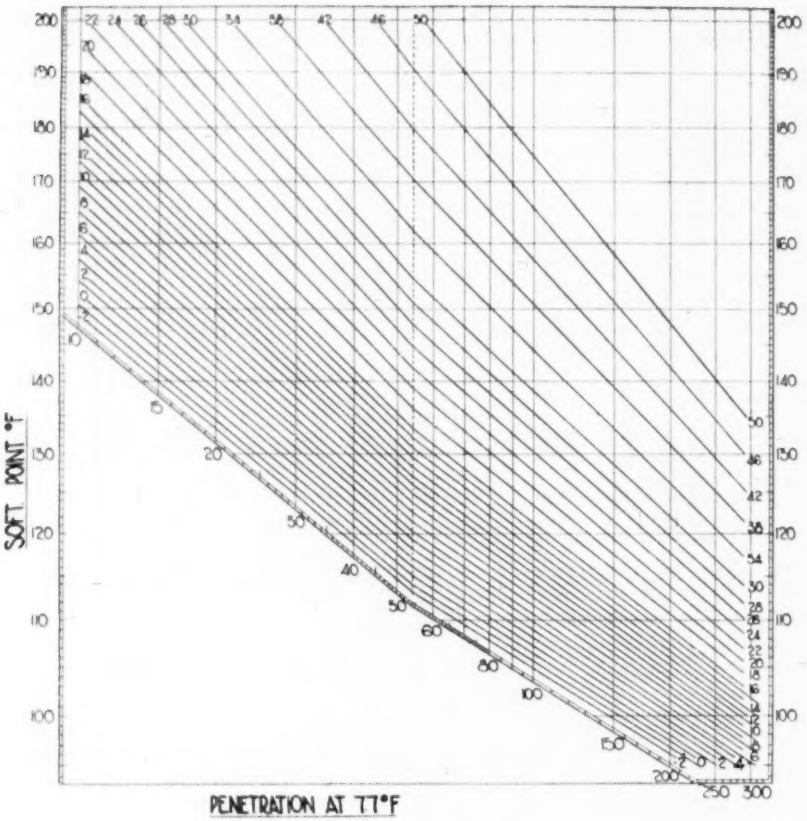


Fig 17

SOFTENING POINT NUMBER CHART

same axes and scales, namely log softening point as ordinate and log penetration at 77° F as abscissa.

In this case a careful study had once more to be made of all the tabulated experimental rheological data in conjunction with the additional Viscosity Number characteristics available at that stage from Fig 14.

Again, it was considered advisable in the first instance not to take into account all data influenced by the dimensions of the penetrometer

needle, that is, to neglect all softening-point data corresponding to penetrations at 77° F below 54. The principle underlying the choice of the position of the Softening Point Number lines was that for "perfectly normal" bitumens—as defined previously—Softening Point Number was identical (within limits of experimental error) with Viscosity Number at any and all of the three viscosity test temperatures 140°, 158°, and 176° F respectively. For this reason too it was necessary to disregard all "abnormal" lines for purposes of constructing the final Softening Point Number chart.

After several attempts using "trial-and-error" principles, the most suitable zero-base line was decided upon, and in addition the position of the line representing 10 Softening Point Number was also selected. The next step was to fill in the intermediate lines on the assumption that a definite mathematical law had to be followed, namely that the lines should be spaced at regular intervals and also that there should be a constant angle of rotation between each pair of successively increasing Softening Point Numbers. This was in accordance with the findings of observation 5b mentioned earlier.

It should, of course, be realized that each attempt at establishing an optimum Softening Point Number chart had again to be followed by the laborious procedure of checking the individual penetration—softening-point relationships of all the samples from Series A to Z, as given in the tables of recorded data.

In order to correct for the changes in the slopes of the lines for penetrations at 77° F below 54, the procedure adopted was identical in principle to that used for the Viscosity Number chart, as indicated in Fig 13.

The merits of this method of classification in relation to other established procedures will also be discussed in Part III together with "Viscosity Number."

Use of the Softening Point Number and Viscosity Number Charts for the Theoretical Determination of Viscosity of Bitumens at their Softening Point Temperatures

As indicated previously, Fig 15 was constructed for perfectly normal bitumens from data derived directly from the Viscosity Number chart in Fig 14. Since for such bitumens, the Softening Point and Viscosity Numbers have been made identical, it follows that data from both charts in Figs 14 and 17 respectively can be incorporated in a single diagram. The lines shown in Fig 15 have consequently been extended to beyond the corresponding softening-point temperatures and the relevant softening points inserted in each line. The remarkable observation was then made that, for a given series of perfectly normal samples of fixed Viscosity Number, all the softening points deduced from Fig 17 lie in one and the same straight line. This once more illustrates the rationality of the author's methods of bitumen classification.

The relevant "softening-point lines" are shown in a composite diagram in the bottom right-hand corner of Fig 15.

This diagram clearly confirms the observations made by the author in Part I in connexion with numerous recorded values ranging from 5000 to 39,000 poises for viscosities of bitumens at the softening-point temperature.

Thus, the viscosity is shown to vary from 1500 BRTA seconds (*i.e.*, about 6000 poises) for bitumens of 20 pen at 77° F to 10,000 BRTA sec (*i.e.*, about 40,000 poises) corresponding to penetrations of 200 at 77° F. Obviously too, these limits can be extended considerably in either direction for bitumens of very low and very high penetrations respectively.

A point of special significance arising from Fig 15 is that the viscosity at the softening-point temperature is dependent to a greater degree on the actual penetration of the bitumen at 77° F than on its index of quality or Viscosity Number.

The greater susceptibility or tendency of normal bitumens of low Viscosity Number (*e.g.*, V.N. = 0) to display greater changes in viscosity (at the temperature of the softening point) with changes in penetration at 77° F is, however, worth noting from the diagram.

As pointed out in Part I, each class of bitumen has a characteristic equation relating the viscosity at the softening point temperature with the softening point itself.

The general equation is :—

$$\log \eta = a - b \log M$$

where a and b are characteristic constants for each class of material.

The following characteristic equations have been derived from Fig 15 for normal bitumens of Viscosity Number or Softening Point Number 0, 5, 10, and 14 respectively :

V.N. = 0 : $\log \eta = 86{\cdot}28 - 29{\cdot}75 \log M$.
V.N. = 5 : $\log \eta = 57{\cdot}20 - 19{\cdot}21 \log M$.
V.N. = 10 : $\log \eta = 54{\cdot}97 - 18{\cdot}35 \log M$.
V.N. = 14 : $\log \eta = 48{\cdot}18 - 15{\cdot}85 \log M$.

In each case the viscosity η is expressed in poises, the R & B softening point M in degrees Fahrenheit absolute, and all logarithms are referred to the base 10.

Derivation of the Softening Point–Viscosity Number Chart

This chart is a natural development of the " Viscosity Number " and " Softening Point Number " classifications. Thus, Figs 14 and 17 can be used for direct correlation of R & B softening points with BRTA viscosities at 140°, 158°, and 176° F respectively, simply by reading the relevant values corresponding to the same penetrations at 77° F on each chart.

This method of bitumen characterization is shown in Fig 18, which exhibits the following interesting facts, in accordance with the basic observations made earlier in this paper :—

1. The slopes of the various lines in each band are the resultants of the slopes due to the Softening Point Number and Viscosity Number lines respectively.

2. The spacing of the lines in each band are also a natural consequence of the spacings adopted for the Viscosity Number and Softening Point Number charts taken in conjunction with each other.

3. The width of the 176° F band measured at any softening point between any two classification numbers is somewhat greater than the

corresponding width of the 158° F band, while the latter, in its turn, is correspondingly wider than the 140° F band.

4. No sharp breaks occur in the slopes of the lines on this chart,

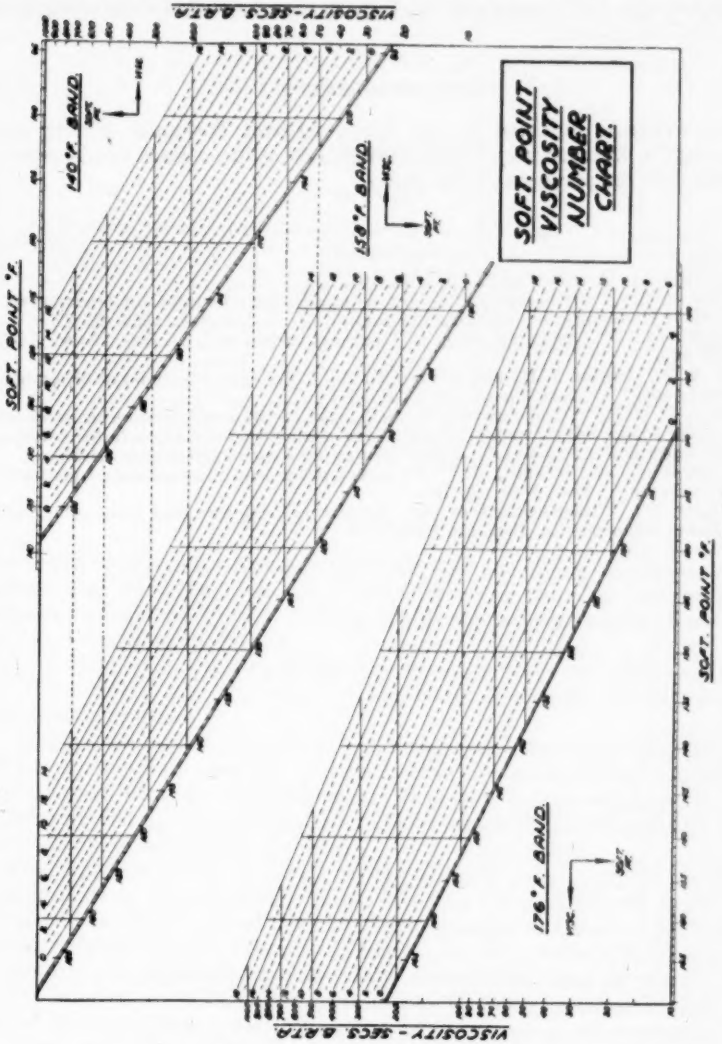


Fig 18

since the breaks shown in Figs 14 and 17 nullify each other, both being due entirely to the same cause—viz., the shape of the penetrometer needle—which, in the present instance, is eliminated.

5. From the methods adopted by the writer for the construction of the three charts for Viscosity Number, Softening Point Number, and

Softening Point–Viscosity Number respectively, it follows that for " perfectly normal " bitumens identical index values should always be obtained irrespective of the temperatures of test.

Appreciable deviations from this hypothesis are attributed to anomalous flow characteristics.

Acknowledgment

The writer is indebted to the South African Torbanite Mining and Refining Co. Ltd. for very kind permission to utilize certain of his experimental data for purposes of this study.

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THE DETERIORATION OF TRANSFORMER OIL

PART II. THE INFLUENCE OF TRANSFORMER CONSTRUCTIONAL MATERIALS

By L. Massey *

Summary

Transformer constructional materials influence the rate of oil deterioration. Experiments to assess this influence, both on an accelerated basis and under conditions approximating to transformer practice, are described. Copper is shown to be outstandingly more active than any other single material, and the reasons governing its activity or non-activity in a transformer have been investigated. Under certain conditions impregnating varnishes are involved in sludge production and lead to erratic oil performance. The precise mechanism involved is not fully understood, but it is believed that it is associated with the formation of oil-soluble copper salts in the interior of coils by interaction between the windings and unpolymerized varnish. The migration of copper from a coil interior to the surrounding oil is proved. Thin films of varnish used to protect exposed metal surfaces are shown to be inert towards oil and to form effective barriers isolating the metal from contact with the oil.

General

In Part I of this paper it was pointed out that one of the requirements for minimizing oil deterioration in a transformer is that the materials of construction should be inert towards oil, particularly with respect to their ability to catalyse oxidation.

In dealing with this subject there are two aspects: the effect of the oil on the material and the effect of the material on the oil—two vastly different approaches.

Simple tests for the behaviour of materials in oil are regularly practised. Specimens are immersed for long periods in hot oil and their properties are recorded before and after the test. The use of a material would not be considered unless it had passed these tests, which also automatically preclude gross contamination of the oil.

The influence of the material on the oil is therefore limited to trace contamination, the only likely effects of which are on electrical properties or on the oxidation rate of the oil. Determination of electrical properties is relatively simple, and is frequently carried out as a matter of routine when the changes in physical properties of the material are being assessed.

The subject to be discussed now is that of catalytic influences, which raises far more difficult questions, many of which cannot be answered. In fact, this is a subject of first importance to the life of an oil in a transformer and is probably the least understood. It is usually impossible to determine analytically traces of organic impurities and, in any case, contact catalysis has to be considered. An obvious approach is to make oxidation experiments in the presence of the material being tested.

* Metropolitan-Vickers Electrical Co. Ltd.

In order to provide data on the subject two major series of tests were undertaken on a range of common materials present in a transformer, one series on an accelerated basis, the other under conditions approximating to those in a transformer. As a result of some of the conclusions derived from these tests further experiments on copper compounds and on varnished electrical coils were made.

Accelerated Oxidation Tests at 150° C

As the conditions for any accelerated test must be very strictly controlled, an obvious and convenient method to use is the BS 148 oxidation test, but replacing the standard copper catalyst by the material under test. The sludge and acidity developed are then indications of the catalytic activity of the test specimen.

Many objections can be advanced against this method, *e.g.*, the high temperature and the fact that all oils will not be equally affected by a given catalyst, but it is desired to emphasize that some definite lead must be given to transformer engineers, very often at short notice.

The method described is not more open to criticism than any other, it gives results in a short time, and the strictly specified and accurately controlled equipment is available in any laboratory dealing with transformer oils.

The oil used throughout these tests was a wartime Class B oil, one drum being reserved for the purpose and identified by the description "A1."

A series of sludge results on typical materials is given in Fig 3. Acid values were also determined, but have not been reported because they were proportionate in all cases except one to the sludge. The exception was solder, which gave a very high acid value in relation to the sludge.

Wherever possible the test specimens were introduced into the flask in a form corresponding as closely as possible in area to the area of the standard copper catalyst. In cases in which this was not possible (*e.g.*, for dry sludge, cotton stripped from insulated wire, etc.) a weight of 0·5 g was used for the test. The tests on varnishes were made by preparing a fully baked double-dipped film on 1 mil tissue paper. (The P.F. type varnish was an oil-modified phenol–formaldehyde varnish, the straight phenol–formaldehyde varnish was of the methylated-spirit-soluble type, and the synthetic varnish was of unknown composition.)

In the case of the oil of acid value 0·31 mg/g this was prepared by oxidizing a sample of the oil "A1" in the BS 148 oxidation test equipment, filtering the oxidized oil, and adding sufficient of this filtrate to a sample of new A1 oil to give the mixture an acid value of 0·31 mg/g.

The data given in Fig 3 are believed to be of practical importance as a guide to the choice of materials, but caution is necessary in their interpretation, particularly as they are not used singly in a transformer.

The inactive nature of dry sludge powder (prepared by sludging oil A1), is interesting in view of a commonly accepted belief that sludge is a catalyst for further sludge production. Oil acids are shown to exert an appreciable effect.

The inactive nature of lead and zinc are surprising in view of the frequent occurrence of these metals in transformer sludges. The reason probably

is that although the two metals are not catalytically active they are attacked under certain conditions by acid oil. Wilson and Garner [1] have shown that pure lead is attacked in oxidized white oils and engine oils, and that this attack is caused by the joint presence of acids, peroxides, and oxygen. The comparatively inactive nature of lead indicated in Fig 3 cannot there-

FIG 3

ACCELERATED TESTS AT 150° C. BS 148 OXIDATION TEST EXCEPT FOR CATALYST

fore be taken as showing the suitability of this metal for use in a transformer.

The surface condition of a metal is shown to be a possible factor—*e.g.*, black sheet-steel is more active than mild steel. Physical structure also appears to play a part, *e.g.*, compare cast and rolled sheet brass. Solder yielded most erratic results.

The Grade 3 pressboard was composed of a mixture of cotton and jute,

and Grade 4 was composed wholly of cotton. Both are widely used as transformer insulants. The cotton and paper stripped from insulated copper wires were examined in order to assess their effect as distinct from the composite effect of coils wound from wire insulated with these materials.

Linseed oil and tung oil have also been used for the treatment of coils. Accelerated tests at 150° C were made on transformer oil to which 1 and 5 per cent of these oils had been added. The results are given in Table I. The acid values are low in comparison with the sludge, and it would appear likely that a large proportion of the sludge was composed of oxidized vegetable oil. The low sludge result for the 1 per cent linseed oil is, however, puzzling.

TABLE I

Accelerated Tests at 150° C *in Presence of Vegetable Oils*

Material	Sludge, %	Acid value, mg/g
1% linseed oil . . .	0·08	0·25
5% linseed oil . . .	1·35	0·90
1% tung oil . . .	0·60	0·35
5% tung oil . . .	3·8	0·65

Two particularly important conclusions emerged from these accelerated tests. The first was that copper and copper-containing alloys are outstandingly the most active materials, particularly so in the presence of acid oils. The second was that the varnish samples exerted a negligible catalytic influence on the oil. These two points will be returned to later.

It also emerged from these tests that in evaluating a material for use in a transformer it is not sufficient to examine the catalytic influence of the material on new oil and the influence of new oil on the material—it is also essential to explore the effect of oxidized oil on the material. This applies particularly to the metals, the results on lead and zinc emphasizing this point. A suitable procedure would be to immerse the test specimen in used transformer oil having an acidity of, say, 5 mg/g and preferably containing some moisture. The oil should then be held at 80° C for several days, after which the condition and loss in weight of the specimen should be determined.

"SERVICE CONDITION" TESTS AT 80° C

As a step towards meeting some of the objections held against accelerated tests and also to form a link between accelerated tests and service performance, a series of experiments was put into progress with the following features: a glass bottle of 1150 cc capacity was charged with 900 cc of oil, and into this was introduced a specimen of the material under test with an area of 10 sq. cm. A clock glass covered the top, but was held up at one point by a bent glass rod. The bottle was immersed in an oil-bath, the oil-level in the bottle being above the oil-level in the bath. The oil-bath was maintained at 85° C for five days a week, and allowed to cool to room temperature for the other two days of the week. In this manner the service conditions of a ventilated transformer were closely approached.

For the greater part of the time, the oil under test was at 80° C, convection currents were induced by the difference in the oil-levels, and air breathed in and out through the gap.

Samples were withdrawn for examination at intervals, and were of a size not to affect materially the oil bulk. (A 40-gal drum of oil was set aside for these tests. This oil was from the same supplier and possessed the same general characteristics as the oil used for the accelerated test. It is identified by the number " A2 ".)

It cannot be argued that any unfairly accelerated conditions are present, but the changes are, of course, comparatively slow.

The specific objects of this test were to furnish quantitative data on the changes occurring in an oil under service conditions, to determine whether the relative catalytic order is the same at 80° C as in the accelerated tests at 150° C, to discover which of the commonly applied tests are the most useful in assessing oil condition, to see if there is any test capable of giving very early indication of the comparative breakdown rates, and finally to find whether the early breakdown indications continue the same relative trends until severe breakdown ultimately occurs.

The materials used were typical items of transformer construction. It is regretted that some were badly chosen, that at least one major omission (that of copper) was made when the tests were started, so that the tests on copper have not been in progress for as long as those on the other materials and that the time factor has prevented these errors being rectified.

The deterioration of the oil was assessed by determinations of acid value, peroxide value, sludge content, and interfacial tension.

It was found that the analytical repeatability of the results in some cases approached in magnitude the difference between the various materials examined. This was particularly so in the case of the sludge results, on account of the difficulties associated with the very small sample permissible for the test and the difficulty in sampling a heterogeneous system. The determination of sludge is also influenced by many factors, *e.g.*, nature of diluent, temperature of precipitation, time of settling, and porosity of the filter. These factors become of particular importance at low values, and a sludge result can therefore be adequately stated only when these factors are fully defined. The results quoted were obtained under the conditions specified in BS 148. For these reasons it was decided not to plot individual results but to give limiting curves, including within their boundaries all the individual figures. This was found to result in the materials falling naturally into groups and to make clearer the general trends by eliminating many confusing detailed results which had no practical meaning.

The results of the tests are given in Figs 4 to 7. (In addition to these data, saponification values were also determined, but as the range was only from 0·1 in the new oil to a maximum of 1·7 after twenty months, it was decided to wait until the test had been in operation longer before tabulating them.)

The materials fall into two main groups—one including many common metals and insulating materials, the other fifteen typical varnishes used in electrical construction. The varnish group has been in progress for a shorter period than the general group.

Fig 4 shows the acid value–time plot. It will be seen that in the general

group all materials cause the formation of more acidity than is formed in the blank oil test (which forms the lower limiting curve for the shaded area), but the differences are relatively small.

The varnish group follows a mean curve similar in form to the general group, but in this case several varnishes cause the formation of less acidity than the oil blank.

Copper is far more active than any other material, and is in a class by itself.

The rate of acidity formation for all experiments decreases with increasing time once the oxidation has commenced, but in this respect also copper

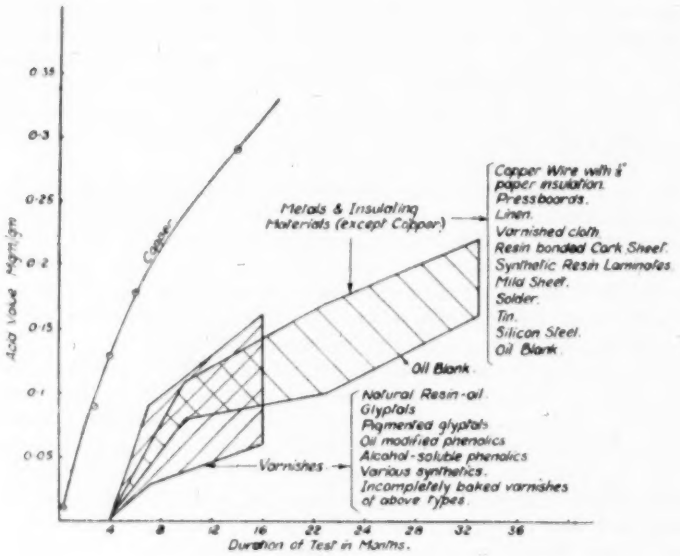

FIG 4

SERVICE CONDITIONS TEST AT 80° C. ACID VALUE–TIME CURVES FOR OIL IN PRESENCE OF VARIOUS MATERIALS (INDIVIDUAL RESULTS LIE WITHIN SHADED AREAS)

differs from the other materials in that there is no induction period, whereas all the other materials show negligible change over the first four months.

Fig 5 gives the sludge–time plot. The mean curve is of similar form to the acid-value curve in that there is an induction period followed by a rapid rate of change, which then decelerates with time.

The sludge results fall on either side of the blank oil curve. It is particularly interesting that the copper value is approximately the same as that for the oil blank. The list of materials given at the right of Fig 5 divides the materials of the general group into those showing negative and those showing positive catalysis when referred to the blank oil test. This division must be accepted with reserve, on account of the high analytical error possible in the sludge determinations and the comparatively small differences in the percentage results.

Fig 6 gives the peroxide value–time plot. The general form of all the curves shows a steep rise during the first two or three months, followed by a steep fall, then another small rise, and finally a slow decline tending to

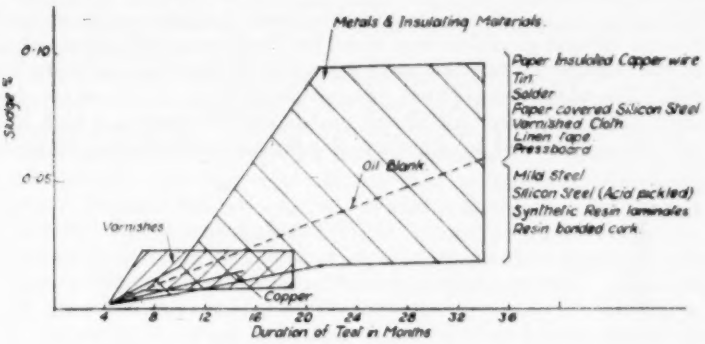

FIG 5

SERVICE CONDITIONS TEST AT 80° C. SLUDGE–TIME CURVES FOR OIL IN PRESENCE OF VARIOUS MATERIALS (INDIVIDUAL RESULTS LIE WITHIN SHADED AREAS)

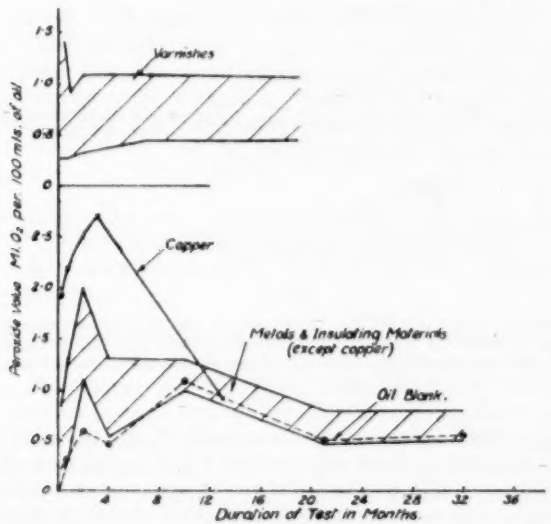

FIG 6

SERVICE CONDITIONS TEST AT 80° C. PEROXIDE VALUE-TIME CURVES FOR OIL IN PRESENCE OF VARIOUS MATERIALS (INDIVIDUAL RESULTS LIE WITHIN SHADED AREAS). MATERIALS AS DETAILED IN FIG 4

flatten out to a constant value. The varnishes tend to minimize these peaks and troughs, but the final values are similar to those in the general series. Copper again falls in a class by itself in giving a much higher initial peak than any of the other materials.

More recent work has shown that oils containing copper begin to develop a peroxide value after 4 hr, and it now appears desirable to explore the region between zero and one week, which was the time of the first determination in the present series.

Fig 7 gives the interfacial tension–time plot. Unfortunately a suitable instrument became available only when the tests were well advanced, and the initial changes for the two main groups have therefore had to be interpolated. The same general form of curve is given for I.F.T. as for sludge and acid value, *i.e.*, after the oxidation has started there is a high initial rate of change, followed by a gradual deceleration with time. As pointed

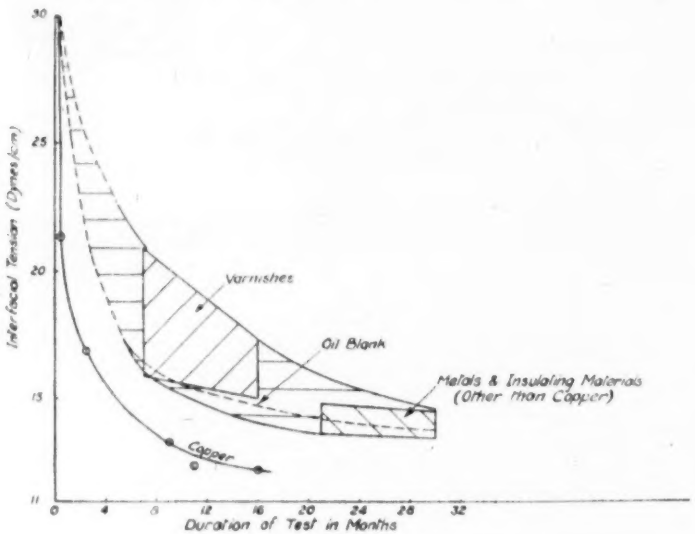

FIG 7

SERVICE CONDITIONS TEST AT 80° C. INTERFACIAL TENSION–TIME CURVES FOR OIL IN PRESENCE OF VARIOUS MATERIALS (INDIVIDUAL RESULTS LIE WITHIN OBLIQUELY SHADED AREAS. PRESUMED OVERALL FORM SHOWN BY HORIZONTALLY SHADED AREA). MATERIALS AS DETAILED IN FIG 4

out, however, no readings were taken immediately after the start of the test, and it is not possible to state whether the I.F.T. indicates any induction period for the two main groups. Copper is again more active than the other materials, and as a complete record is available in this case it is possible to state that if there is any induction period it occurs before the first reading at one week.

It will be seen from Figs 4 to 7 that the rate of oxidation of the oil is very slow owing to the non-accelerated conditions, but it is believed that sufficient data have been obtained during the thirty months of operation of the test to enable some tentative conclusions to be drawn :—

(i) Copper is by far the most active material when assessed by acid value, peroxide value, and interfacial tension, but within the time

limits of the test it has not accelerated sludge formation as referred to the oil blank.

It would appear that although copper is in a class by itself as an oxidation catalyst, it favours (under the conditions of the " service conditions " test at 80° C) the production of oil-soluble products rather than oil-insoluble sludge.

On the other hand, in the accelerated tests at 150° C copper was proved to be outstandingly the most active catalyst as assessed by sludge production. Though the conditions of the two tests vary in other respects, it is suggested that this difference is essentially one of temperature and oxygen access, and that as temperature and oxygen access decrease the ratio of acids to sludge increases. This suggestion is based on the conclusions derived from experiments using the BS 148 oxidation test method to produce temperature–oxidation-products curves and rate-of-air-flow–oxidation-products curves. (These are to be described in Part III.)

Assuming the mean molecular weight of acids formed by the oxidation of oil to be 185, the ratio of acids to sludge obtained in the " service conditions " test on copper at 80° C is 6 : 1. The corresponding ratio obtained on the same oil in the standard BS 148 oxidation test is 0·5 : 1.

(ii) All the materials other than copper yield curves for all properties which lie very close to the corresponding curves obtained in the oil blank test, *i.e.*, these materials have caused negligible acceleration of the degree of oxidation. Some of the varnishes have in fact retarded slightly the oxidation. This is not impossible, for some varnish constituents such as free phenols are known to function as inhibitors.

These conclusions for the " service conditions " test agree broadly with the results of the accelerated tests at 150° C given in Fig 3.

The mean ratio of acid to sludge in these service tests on materials other than copper was about 1 : 1.

(iii) The peroxide value and interfacial tension results after a few weeks can be taken as a guide to the development of sludge and acidity after thirty months. The tests are being continued until severe breakdown occurs to see whether this correlation is maintained.

(iv) The mean acid value for all materials (excluding copper) after $2\frac{1}{2}$ years was 0·18 mg/g. This is not an unreasonable figure for a heavily loaded open-type transformer after a similar period in service, and shows that the tests are giving results comparable to service conditions.

The general form of the acidity curves, the consistency of the analytical figures, and the ease of determination also justify the almost universal industrial use of the acid value as a means of assessing the degree of deterioration of a used oil.

It is interesting to compare these results with similar determinations made on oils in service. Table II lists the characteristics of a number of used oils after periods of service in transformers. Unfortunately the full

history of the conditions of loading, etc., of these oils is not known, but the results are of some value in that they show that the changes recorded in the 80° C tests also occur in service. There is one exception. In the 80° C tests the peroxide value rapidly reached a peak, after which it gradually fell, and it could be inferred that after long periods of service in a transformer the peroxide value of the oil would be negligible. The service results sharply contradict this. Whereas the peak in the 80° C tests was about 1·7 (except for copper) the oils taken from transformers all showed much higher values, in one case reaching 50. Further investigation is obviously desirable.

TABLE II

Characteristics of Oils in Service

(Oils taken from non-conservator transformers)

Ident. no.	Class of oil	Time in service (years)	Acid value, mg/g	Sap. value, mg/g	Peroxide value, ml O_2/100 ml oil	Interfacial tension at 20° C, dynes/cm
1	B	New oil 2 yr in drum	0·02	—	0·9	29
2	B	13	0·08	2·3	10·8	16·2
3	B	11	0·10	3·7	1·5	16·6
4	B (probably)	28	0·15	1·2	1·9	16·3
5	American trans. oil	33	0·20	0·5	10·0	15·8
6	B	11	0·23	7·4	6·2	14·3
7	B	18	0·43	4·4	13·4	12·3
8	Low sludge B	10 yr (last 5 idle)	0·49	6·9	2·5	13·0
9	B	15	0·63	11·3	17·1	12·9
10	A	16	0·64	2·4	1·2	11·3
11	Low sludge B	10	0·85	9·3	20·0	10·9
12	„ „ B	10	0·90	6·0	20·0	10·0
13	B	15	1·01	8·9	10·0	11·8
14	A	12	4·5	18·5	51·0	9·6

INFLUENCE OF COPPER

The data so far presented should be of some value in selecting transformer materials to ensure maximum life in the average transformer, but a large part of the chemical interest given to oils is not on account of the slow steady deterioration experienced over long periods by an average transformer—it is because of the excessively rapid and unexplained breakdown which occurs in a small proportion of cases.

The results of the tests were therefore carefully considered to see if they offered any contribution to this problem. Two of the findings appeared to warrant further investigation. First, the outstanding catalytic activity of copper suggested that it was probably the only single material capable of producing the major acceleration of the oxidation rate of oil occasionally observed in transformers. Secondly, the results showing the inert behaviour of varnish films needed amplifying in view of the general belief that varnishes were occasionally involved in service breakdowns.

If copper is the cause of severe breakdown, then it follows that it must occasionally function erratically, for copper is used in large quantity in all transformers. The problem is to find a reason for copper being inactive in the great majority of transformers and active in a small minority. In a transformer there is a very small surface area of copper in the form of leads and straps. These are generally varnished or painted to seal them from contact with the oil, and the soundness of this practice has been well established by many tests proving that the varnish is a wholly effective barrier.

If these leads are left exposed they will exert a catalytic influence pro-

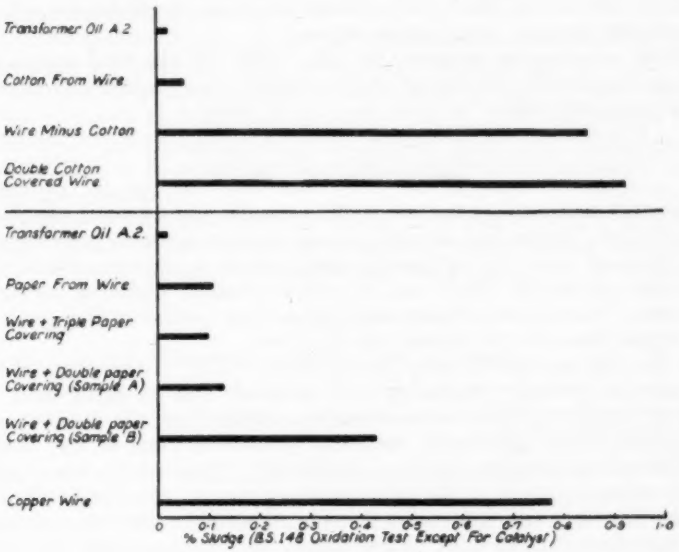

FIG 8

INFLUENCE OF COTTON AND PAPER INSULATION ON THE CATALYTIC ACTIVITY OF COPPER WIRE

portional to their area, but the behaviour is not erratic. It is probable that small areas of exposed copper metal on a transformer will influence and modify to some extent the slow, steady rate of oil deterioration in a normal transformer, but cannot explain the major deterioration in abnormal cases.

The bulk of the copper in a transformer is, of course, present in the coils, and in this case there are several features of construction which can conceivably lead to erratic oil performance.

In most large transformers the coils are wound from paper-insulated wire. In Fig 8 is shown the sludge values by the accelerated test at 150° C on oil containing copper wire insulated by various thicknesses of paper. The results show that with the greater thickness of paper the copper influence is negligible, but this influence increases with decreasing thickness, and also

varies from sample to sample of paper of a given thickness. How far the time factor will influence the result is not certain, but a length of triple paper-covered wire was included in the " service conditions " test at 80° C, and after 2½ years it had caused negligible acceleration of the oxidation rate. The protective influence exerted by paper insulation is therefore an obvious factor in oil performance.

It is also interesting to speculate on the nature of the catalysis. It is certain that in the case of thin or porous layers of paper the copper is still active, and the most obvious mechanism is the formation of soluble compounds at the copper–oil interface which diffuse through the paper into the oil.

Fig 8 also shows clearly that cotton exercises no protective influence, presumably because of its porous nature.

These experiments suggest that the nature of the wire covering can influence materially the rate of oil deterioration in a transformer employing oil-impregnated coils.

Influence of Varnish

In small transformers the coil is often varnish impregnated, the purpose being to give mechanical strength, to seal against moisture penetration, to keep the coil clean during manufacture, and to anchor the fibres to the cellulosic insulation which can so seriously affect electrical breakdown strength. Some manufacturers also realize that varnish sealing can isolate the copper from the oil, a very vital function.

In the 150° and 80° C tests the catalytic activity of thin films of many commercial insulating varnishes was assessed, and in every case their activity was negligible or even negative. Apart from the results quoted, many other tests were made, including accelerated tests at 150° C in the presence of varnish films baked on copper foil. These results were approximately equal to those on the oil without copper, *i.e.*, the varnish formed a perfect barrier. Other tests were made in which a free film of varnish was introduced additionally to the copper, and in these cases the normal sludge value was given.

The whole trend of these results on completely dried varnish films was to indicate their inert nature.

On the other hand, these findings contrasted with many indications from oil in service that varnish was a factor in sludging. It therefore seemed desirable to determine the effect of a varnish-treated coil on the sludging of an oil.

Two series of 2-inch-diameter coils were wound, one series with double-paper-insulated copper wire, the other with double-cotton-covered copper wire. These coils were impregnated by the hot-dip method, with the varnishes used in the previous tests, *i.e.*, the coils were pre-dried, and then while hot were immersed in cold varnish for ½ hr, then drained, and finally baked at the varnish-maker's recommended time and temperature. These coils were immersed in transformer oil contained in a Pyrex glass beaker and then placed in an oven at 100° to 105° C for sixteen days.

The hot-dip treatment is not the best process for impregnating coils. However, it is one which is often practised industrially, and it offered more

possibility of exploring the behaviour of varnish-treated coils and of differentiating between them than did coils which had been fully impregnated by vacuum-pressure treatment followed by complete sealing.

At the end of the test period the acidity and sludge content of the oils were determined, after which the oil was filtered and then subjected to the BS 148 oxidation test but without the presence of the usual copper-foil catalyst. Blank tests were also made on the oil alone and on oil containing untreated cotton- and paper-insulated wire coils.

A large number of tests were made by this method on twelve different varnishes, but the results of duplicate and repetition experiments were found to be widely inconsistent, not only on the varnish-treated coils but also on the untreated coils.

The conditions of oxidation employed in these experiments were not ideal. Temperature gradients are difficult to avoid in ovens, and the rate of air flow over beakers heated in ovens is also likely to vary to some extent. Accurate control over both these factors is vital if good repeatability is to be achieved. The variations of the test results were, however, far outside the limits likely to be caused by the comparatively small variations in the experimental conditions.

An analysis of the detailed results showed there was nothing to be gained by quoting them in full, but by grouping the results certain broad conclusions became apparent. These grouped results are given in Table III.

TABLE III

Oil-immersed Coil Test Range of Results

Sample	Oil at conclusion of immersion test (16 days at 100° to 105° C				BS 148 oxidation test results (without copper) on filtered oil at conclusion of immersion test			
	Sludge, %		Acid value, mg/g		Sludge, %		Acid value, mg/g	
	Min	Max	Min	Max	Min	Max	Min	Max
Original oil	—	—	—	—	—	0·08	—	0·1
Blank test, *i.e.*, oil with no coil	nil	0·006	nil	nil	0·03	0·15	nil	0·4
Oil with double-cotton-covered wire coil	0·02	0·41	0·05	0·7	0·14	0·84	0·2	1·1
Oil with double-paper-covered wire coil	0·15	0·61	0·06	2·2	0·29	0·71	0·65	1·3
Oils containing double-cotton-covered wire coils impregnated in twelve different varnishes	0·002	1·54	nil	2·0	0·14	1·45	0·4	4·2
Oils containing double-paper-wound wire coils impregnated with twelve different varnishes	0·001	1·76	nil	1·4	0· 7	0·95	0·2	2·8

As an example of individual sludge figures and of the range of varnishes used, Fig 9 gives the detailed results of one series of experiments.

The following facts emerged :—

(i) The oils in the blank tests developed no acidity and negligible sludge. After filtration these oils also yielded low sludge and acid values when tested by the BS 148 oxidation test in the absence of copper.

(ii) The oils containing unvarnished coils developed substantial amounts of sludge and acidity. After filtration these oils yielded substantial sludge and acidity in the BS 148 oxidation test in the absence of copper. The results were inconsistent. Exceptionally, one cotton-insulated wire coil developed only very low sludge and acidity and also gave very low values after the BS test.

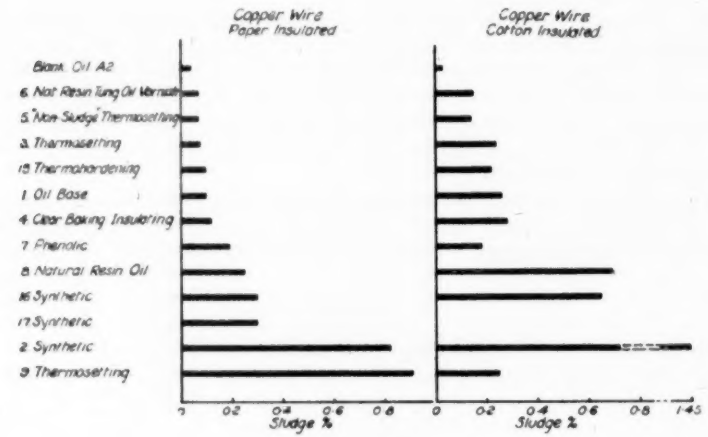

FIG 9

DIAGRAM SHOWING SLUDGE VALUES ON OIL A2 AFTER IMMERSION THEREIN OF VARNISH-IMPREGNATED COPPER WIRE COILS FOR SIXTEEN DAYS AT 100° C (BS 148 TEST, WITHOUT COPPER, ON FILTERED OIL)

(iii) The varnished coils yielded a wide range of results, varying from answers comparable to the oil blank to values greatly in excess of those on the unvarnished coils. After the BS 148 oxidation test in the absence of copper a wide range of results was also recorded, but the values were not proportional to those obtained on the corresponding unfiltered oils, *e.g.*, an oil with a high sludge formed during the exposure period of the test could give a low result after the BS test, and vice versa. Moreover, the variations were not always related to the nature of the varnish, but could occur in duplicate tests on one varnish.

(iv) The relation between sludge and acidity was most erratic. Some high sludges were associated with low acidities.

The wisdom of recording these experiments with their widely erratic results may be questioned, but it is believed that the inconsistency is in itself a vitally important observation. The work was carried out carefully under laboratory conditions, and every effort was made in planning and executing the programme to ensure the identity of conditions. If in these

circumstances such wide variations are possible, then it must be considered possible that similar inconsistencies will be experienced in transformer practice, for a transformer is essentially a coil of insulated wire immersed in oil, and manufacturing conditions cannot be as closely controlled as these laboratory experiments.

The most important practical conclusion from these experiments is that the presence in transformer oil of a varnished coil can be an important factor in sludging phenomena, and a cause of erratic performance of the oil. A second conclusion of importance when considering mechanism of deterioration is that the presence of these coils introduces soluble catalysts into the oil, this being proved by the high values for sludge and acidity obtained on the filtered oil by the BS 148 oxidation test.

Further investigations to elucidate the mechanism of oil deterioration under these conditions is desirable, but pending further work it is believed that the following paragraphs are a fair comment on the problem :—

Varnish impregnation of coils has never rested on a very satisfactory basis. In the first place the conventional varnish contains roughly 40 per cent of solvent, and after the coil has been impregnated this solvent has to be removed. This leaves a porous structure. Secondly, penetration is not always complete, and often the core of a coil remains dry, again leaving air-filled spaces, both in the cellulosic insulation and between turns. These facts are well known, and very high voltage coils are oil impregnated and not varnish treated.

Thirdly, another important factor is that many varnishes, particularly the older oleo-resinous type, depend on oxygen for their hardening. Oxygen access to the coil interior is limited, and the varnish therefore tends to remain in a liquid condition, in which state it is likely to contain active chemical constituents which are not present in a fully baked film.

In the fourth place, it is extremely difficult to eliminate solvents from the coil interior, and these hinder the hardening of the varnish, and may even supply chemically active compounds.

There are four results of this state of affairs :—

(i) As the coil cycles in temperature during use, oil will breathe in and out. The presence of a good surface coat of sealing varnish will hinder this breathing, but ultimately cracks are bound to occur, and although oil penetration may be delayed, it cannot be delayed indefinitely.

(ii) It is possible for reactive varnish constituents to be present in the coil owing to incomplete baking, and some of these may attack the copper, causing the formation of oil-soluble products.

(iii) Liquid or incompletely polymerized varnish if present may be oil-soluble.

(iv) If it is accepted that oil breathes in and out of the coil, then it follows that it is possible for soluble varnish and for reactive products from the oil-copper interface to be carried from the coil interior to the main oil bulk.

Experimental corroboration of this breathing mechanism was sought. The analytical problem involved in determining the transfer of organic compounds from a coil interior to the surrounding transformer oil were

very great, but the determination of copper was a fairly simple matter. The filtered oils from the immersed-coil tests described previously were examined for soluble copper, and the sludges formed in the oils during the test were examined for combined copper. The results given in Table IV were obtained. Maxima and minima only are reported as being sufficient to establish the point desired.

TABLE IV

Migration of Copper from Varnished and Unvarnished Coils to Surrounding Transformer Oil after Immersion of the Coils for 16 *Days at* 100° C

	Soluble copper content of oil, p.p.m.		Total weight of copper in sludge, in mg		Percentage of copper in sludge	
	Min	Max	Min	Max	Min	Max
Original oil . .	—	>0·1	—	—	—	—
Unvarnished coils .	0·25	0·37	0·5	9·7	0·1	0·3
Varnished coils .	0·25	1·25	0·1	13·4	0·05	0·2

It will be seen that although the original oil was almost copper free, the filtered oils after exposure to varnished and unvarnished coils for sixteen days at 100° C contained up to 1·25 parts of copper per million of oil, and the sludges filtered from the oils contained copper up to a maximum of 0·3 per cent of copper (corresponding to a total weight of copper in the sludge of 13·4 mg). These experiments yielded conclusive proof of the transfer of copper from the windings of a coil to the oil surrounding the coil.

An interesting observation was made that some correlation appeared to exist between the acid value and the amount of copper in the sludge, suggesting that copper was present in the sludge not as a result of its catalytic function but because of straightforward acid attack on copper metal, *i.e.*, the presence of copper in sludge is a secondary result of acid development.

It has already been proved that the presence of vegetable drying oils in transformer oil leads to the formation of sludges presumably containing oxidized vegetable oil (Table I).

It is believed that these experiments are strong corroboration of the suggestions concerning the mechanism of deterioration of oil in contact with varnish outlined in the foregoing.

The factors influencing erratic performance in oil-containing varnished coils are many. The degree of baking, the efficiency of the impregnation, the efficiency of sealing, the percentage of solids in the varnish, the presence of residual solvents, the nature and thickness of paper and cotton insulation, and the severity and frequency of the temperature cycling are all factors which cause differences in the behaviour of a number of coils all prepared from the one varnish. Under the best conditions this varnish may yield a coil exerting no deteriorating effect on the oil, under the worst the coil may promote heavy sludging.

These differences may occur with one varnish.

Ten or fifteen years ago impregnating varnishes fell for the most part into two main classes, the linseed oil–tung oil–natural resin type and the

spirit-soluble phenolic type. Of recent years many synthetic-resin types have become available, *e.g.*, oil-modified phenolics, glyptals, urea resins, melamine resins, amino resins, and styrene–oil copolymers. It is not likely that all coils treated with these diverse types will behave in the same way, and there is little experimental record of the behaviour of typical examples of these classes on oil deterioration over long periods.

Many of them, particularly those with thermo-hardening properties, should be superior to the older oleo-resinous types and mark a forward step in progress, but the mere increase in the chemical types available multiplies the number of factors to be considered when choosing a varnish and processing a coil.

It will be appreciated from the foregoing account that in coils of both the dry and varnish-treated types there are a number of complex chance factors, many of them associated with the catalytic activity of copper and the access of oil to the copper surfaces. Erratic oil performance in apparently similar transformers is an obvious result.

Before concluding this section on varnishes, there is one point of practical importance it is desired to make. In a transformer the major oxidation changes do not begin until a trace of acidity is formed. With new oils this induction period may last for years. In the presence of unpolymerized varnish in incompletely baked coils, with a varnish of a type capable of producing oil-soluble copper compounds, there is produced soluble copper which may quickly find its way into the oil. This eliminates the induction period, and the oxidation changes can start from the day of the original fill-up of the transformer.

The varnishes considered in this paper were carefully chosen materials recommended by their manufacturers for oil immersion and which, judged by the usual standards, were not affected by oil. No consideration has been given to varnishes which contaminate by direct solubility of the dried film.

Although varnishes may in some cases be associated with an acceleration of the rate of oil oxidation, the opinion is strongly held that the use of varnishes as a barrier between copper and oil is one of the soundest approaches to the problem of minimizing oil deterioration.

The practice of treating exposed surfaces not only of copper but also of the container tank appears to be fully justified, the only limitation in this respect being the special conditions attached to metal surfaces above the oil-level. In this case the resistance of the varnish or paint to a condensate containing water, oil acids, and condensed low-boiling-point fractions of oil is a particularly difficult requirement to meet, and a varnish-based coating for the lid of a transformer must be carefully evaluated for its corrosion resistance. This is a special problem, and is not primarily one of assessing the catalytic influence of the varnish film, although corrosion failure in this case will inevitably result in the corrosion products falling into the oil and raising a new crop of catalysis problems.

Part III of this paper will deal principally with the BS 148 oxidation test and the assessment of oxidation stability of transformer oil.

Reference

[1] Wilson, B. S., and Garner, F. H. *J. Inst. Petrol.*, 1951, **37**, 225.

OBITUARY

Leonard Gowan Gabriel

It is with great regret that we record the death of Leonard Gowan Gabriel on February 28, at the early age of fifty-one. Leonard Gabriel, or L. G. as he was known to his business colleagues, obtained an Honours B.Sc. at London University and held Fellowships of the Royal Institute of Chemistry and the Institute of Petroleum. He was also a member of the Faraday Society. He specialized in the colloid chemistry, and after leaving the University he obtained a post as research chemist with a firm of consultants.

In 1925 he joined the technical staff of Colas Products Ltd. and within a short time became chief chemist of that Company.

In the early days of the road emulsion industry Leonard Gabriel played a great part in the development of the labile, stable, and semi-stable emulsions and the present-day technical excellence of the products of the road emulsion industry is in no small part due to his activities.

In 1933, in collaboration with Prof F. H. Garner and A. J. Prentice, he published "Modern Road Emulsions," a publication which has been recognized by all the leading authorities in the road world as a text-book for emulsion manufacture and application. In addition, he did valuable work in his capacity as Chairman of the Technical Committee of the Road Emulsion Association for many years, and it was in this capacity, coupled with his position of chief chemist of the Colas Company, that his work brought him into contact with experts from all over the world, by whom he was regarded as a man of outstanding ability.

In 1935 he became technical manager of Colas Products Ltd., and shortly before the 1939 war he became interested in some work which was then proceeding in Germany in connexion with coloured bitumen dispersions. In collaboration with J. A. Rawlinson during the immediate pre-war period he produced a range of these products which were originally developed as anti-glare dressings for use on concrete highways. They were, however, found by the Royal Aeronautical Establishment, Farnborough, to be suitable for camouflage purposes, and when war broke out in 1939 there was an immediate demand for large quantities of these materials, which ultimately became known as camouflage paints.

This work brought Leonard Gabriel in close contact with the paint industry, and during the war he served on many of its committees, later becoming a member of the Paint Research Association.

In 1940 he became the technical director of Colas Products Ltd., and in spite of the manifold activities he was engaged upon during the war period, he found time to plan the technical work of the Company for the post-war era.

Leonard Gabriel had great artistic ability, and this gift found expression in his great love of music and photography. He was an accomplished pianist and broadcast with Colin Horsley on the works of the Russian composer Scriabin. Some of his photographic studies were exhibited by

the Royal Photographic Society in their Annual Exhibition. He was a well-known figure at the Savage Club.

Leonard Gabriel possessed a keen sense of humour which stood him in very good stead when acting as chairman of the many technical committees with which his work brought him into contact. He was always at his best when highly technical debate was the subject of the day, and the ability with which he contrived to produce constructive recommendations from a complicated debate was the admiration of all who knew him.

He was cremated at Golders Green on March 1 in the presence of his family and a few intimate friends. He leaves a widow, a son, and a daughter, to whom our sincere sympathy is extended.

T. W. M.

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Oilfield Exploration and Exploitation

Geology

849. Space-time concept in subsurface geology. L. W. Le Roy. *World Oil*, Jan. 1952, **134** (1), 74.—The need for interpreting subsurface geological problems in terms of both space and time is emphasized.

Time surfaces can cross lithofacies boundaries, and the spatial components which control facies relationships must be carefully considered in the determination of these surfaces.

Six references are included. C. A. F.

850. New tool for the wildcatter. Anon. *World Petrol.*, Mar. 1951, **22** (3), 64.—The construction and use of the Dip Logger is briefly described. The instrument, which is used in boreholes, records the surface irregularities of the borehole walls, from which the dip of the formations can be determined.

By measuring the vertical distance between corresponding peaks and troughs on a series of records the dip of the formations can be rapidly computed. Dip direction is also recorded.

The technique has been extensively tested in areas of flat-lying beds and folded and faulted areas.

A diagram of the instrument and examples of logs are given. C. A. F.

851. Graptolites of Athens shale. C. E. Decker. *Bull. Amer. Ass. Petrol. Geol.*, 1952, **36** (1), 1–145.—The type locality of the Athens shale is an exposure 1½ miles northeast of the city of Athens, Tennessee. Author, who is Research Professor Emeritus in Paleontology, University of Oklahoma, presents the result of the study of many hundreds of graptolites collected by zones from most of the fossiliferous outcrops of the Athens shale over a wide area extending from central Alabama across northwestern Georgia and eastern Tennessee to northern Virginia.

The Athens shale has had a long and variable history which began in the upper part of the mid-Ordovician.

The crowning feature of this study is found in the fact that a large and characteristic part of the Athens graptolite fauna extends westward from the southern end of the Appalachian Valley into the Womble of Arkansas, the " Stringtown " of Oklahoma, and the upper Bromide and lower Viola of the Arbuckle Mountains. In this last locality the stratigraphic relations of the Athens graptolite fauna indicate that it belongs in the upper part of the lower Trenton and in the middle Trenton far above the Chazyan where it has been placed for many years. Thus, the Athens graptolite fauna is exactly where Ruedemann definitely placed its equivalent, the Normanskill fauna of New York and New Jersey and the Athens of Alabama, when he described the Normanskill fauna of New York. E. N. T.

852. Geology of the Elk City field. R. J. Beams. *World Oil*, Jan. 1952, **134** (1), 67.—The Elk City field in Washita and Beckham counties, Oklahoma, was discovered in 1947 by J. G. Walters 1, which was completed for 470 b.d. of 65·4° oil and 5650 M.c.f. gas/day from 9260 to 9360 ft. Subsequent development has proved several Pennsylvanian Missouri reservoirs between 8800 and 10,600 ft. Proven productive area, from 111 wells, is 9½ miles by 2 miles.

The structure is an anticline in the southern part of the Anadarko Basin. Within the Pennsylvanian Missouri the anticline is elongated and trends northwest for 12 miles with a productive closure of approx 530 ft and flank dips averaging 4½°. No faulting is apparent. Pays are granite wash and conglomerates having a variable distribution, thickness, and permeability. Porosity ranges from 19·8 to 15%, and connate water from 33 to 40%. Initial bottom-hole pressures range from 3850 to 4350 p.s.i. and oil gravity is 42° to 63°.

The field was unitized in 1951 to facilitate pressure maintenance.

A location map, structure map, and stratigraphical table are included. C. A. F.

853. Glenmora field, Rapides Parish, Louisiana. F. W. Bates and R. R. Copeland, Jr. *Bull. Amer. Ass. Petrol. Geol.*, 1952, **36** (1), 146–59.—The Glenmora oilfield is in the extreme south-central part of Rapides Parish, Louisiana.

It is located geologically along the deep Eocene Wilcox trend, and was discovered in 1950.

The location of the structure was a result of gravity-meter and later seismograph exploration conducted in 1947. The producing section lies more than 2000 ft below the top of the Wilcox series, and at present consists of two main sand zones and several " stray " sands. The structure is a combination of a terrace-type feature and local sedimentary traps. Very little closure or reversal against normal regional south dip can be demonstrated. The productive area thus far established encloses approx 500 acres, with an original total ultimate-recoverable reserve of about 2,250,000 brl proved.

E. N. T.

854. Exploring for Pennsylvanian reef reserves in West Texas. S. Harris. *World Petrol.*, Mar. 1951, **22** (3), 40.—Exploration for Pennsylvanian reef accumulations in West Texas in recent years has shown a broad reef trending southwest to northeast through Howard, Mitchell, Scurry, Borden, and Kent counties. The oilfields which have been found, such as those in Scurry County, have thick pays which yield a high recovery per acre.

Location of the reefs is difficult. Little or no relief is seen on beds overlying the reefs, and core drilling gives unsatisfactory results. Most of the fields have been discovered by drilling on seismic reflection anomalies, and it is necessary to obtain reflections from the pre-Permian in order to detect the reefs.

In the seismic exploration of the area it is recommended that a close shooting pattern using modern equipment with flexible response should be used; detectors should not be over " mixed." All dips, regardless of magnitude and direction of dip, should be plotted, and all data very carefully checked.

In the anomalies, reefs may be differentiated from deep-seated folds by the absence of reflections from the reef core, whereas deep folds show reflections becoming steeper with depth.

A location map, and geological and reflection cross-sections are included. C. A. F.

855. Principal types of oil and gas occurrences in Western Canada. E. W. Shaw and G. C. Wells. *Proc. Geol. Assoc. Canada*, 5.3.51, 19–29.—Oil and gas fields in Western Canada can be divided into six types. These are the foot-hills type, bioherm and biostrome reefs, stratigraphical and structural sand traps, stratigraphic sand traps, and unconformity traps.?

In the foot-hills type, as at Turner Valley in southern Alberta, the structure is complex, involving thrust faults which flatten out at depth into bedding-plane faults. Turner Valley produces from the Mississippian, which consists of a series of overthrust fault blocks.

Fields which produce from bioherm reefs include Leduc, Redwater, and Stettler. The reefs, which are dome-shaped organic accumulations, may be limestone or dolomite, and oil, water, and gas relationships vary greatly.

Biostromes are platform carbonate deposits showing a fairly uniform thickness and passing laterally into other rock types; they may be underlain by bioherms. Excelsior D-2 and the D-2 Flint field in Alberta produce from Upper Devonian biostromes.

A number of oil and gas fields have been found in Alberta in stratigraphical traps in Cretaceous, Trias, and Jurassic sands. Many of these sands overlie erosional unconformities and are spacially controlled by buried highs. The Gilbert pool, which produces from basal Lower Cretaceous sand, is of this type.

Stratigraphical sand traps have been found in various members of the Middle and Upper Cretaceous where the sand shales out to the east, for example, the Viking–Kinsella field between Lloydminster and Edmonton.

Several oilfields have been found in porous limestone or dolomite underlying major unconformities, as at Whitelaw (Trias) and South Princess (Blairmore).

A location map of the oil and gas fields of Alberta, a geological cross-section from the southern foot-hills of the Rockies to Manitoba, and a cross-section illustrating different types of trap are included. C. A. F.

856. Gulf wildcat in Canada. Anon. *World Petrol.*, Oct. 1951, **22** (11), 64.—A well drilled approx 8 miles south of the Stettler field in Alberta found Devonian D_3 pay at 5175 to 5211 ft. Estimated production on test was 1700 b.d. of 30° oil. C. A. F.

857. Significance of Cretaceous oil discoveries in central Alberta. C. W. Hunt. *World Oil*, Jan. 1952, **134** (1), 233.—Only 5% of the known fields in central Alberta produce from the Cretaceous. Bulk of Cretaceous production is gas, and all the pays are sand.

The three largest fields in the plains region are the Campbell, Joseph Lake, and Lloydminster fields; all produce from stratigraphical traps, where permeability barriers are the main accumulation control.

The Campbell field produces from four zones in the Ellerslie Blairmore at approx 3700 ft; oil gravity is 29° to 35°, and pay averages 22 ft.

The Joseph Lake field produces from a zone in the Colorado Viking at approx 3200 ft; oil gravity is 36° to 38°, and pay averages 13 ft.

The Lloydminster field produces from sand zones in the Blairmore at 2000 ft; oil gravity is 13° to 16°, and pay averages 15 ft.

The Cretaceous oil is similar to the underlying Devonian oil, and the central plains area can be divided into "black" oil and "light" oil regions along a line which coincides with the east–west changes from the reef embayment to the reef shelf. This change in oils may be due to change in reef terrane; this would require the migration of low-gravity oil through dense shale barriers between the source and the known positions of the oil. In the Edmonton–Stettler area the high-gravity Cretaceous oil appears to be limited to the area of the Upper Devonian reef embayment. Eastern and southeastern limits of this oil have been found at the edge of the reef shelf.
C. A. F.

858. New Canadian discovery. Anon. *World Petrol.*, Oct. 1951, **22** (11), 64.—A well approx 30 miles northeast of Red Deer, Alberta, tested 50 brl/hr of 38·8° oil from the D_2 at 6227 to 6231 ft. C. A. F.

859. Saskatchewan discovery. Anon. *World Petrol.*, Oct. 1951, **22** (11), 64.—Dahinda 1, 12 miles north of Omega, found oil in a 10-ft pay near the top of the Charles–Member limestone at 4594 ft. The oil is lighter than that at Lloydminster.
C. A. F.

860. Saskatchewan deep test abandoned after failure. Anon. *World Oil*, Jan. 1952, **134** (1), 251.—Big Muddy 1, the deepest well in Saskatchewan, was abandoned at about 10,000 ft. Valuable subsurface data were obtained on the Williston Basin in southern Saskatchewan. C. A. F.

861. Completes second producer. Anon. *World Petrol.*, Mar. 1951, **22** (3), 68.—Guere 2, Anzoategui, Eastern Venezuela, was completed for 456 b.d. of 33·6° oil from a pay at 7846 to 7866 ft. Three other potential pays have not been tested. C. A. F.

862. YPF reports discovery. Anon. *World Oil*, Jan. 1952, **134** (1), 254.—A new field is reported at Campo Duran, San Martin, Argentina. The discovery well is reported to have produced approx 11,000 b.d. from 11,853 ft, the deepest pay found in Argentina. C. A. F.

863. New German exploratory test reaches 2950 ft. Anon. *World Oil*, Jan. 1952, **134** (1), 254.—Wolfskehlen 2, in Western Germany, found traces of gas in Lower Miocene Hydrobien which was productive in the first well drilled on the Wolfskehlen structure. The well was bottomed at 2950 ft.

A third well is being drilled on the structure. C. A. F.

864. Exploration reveals oil in Upper Austria zone. Anon. *World Oil*, Jan. 1952, **134** (1), 254.—It is reported that oil deposits in Upper Austria may be as productive as those in the Zisterdorf area in Lower Austria. There are accumulations in the area of Reid, Bad Hall, and Gmunden, bordered by the Salzach and Mattig rivers.

Exploration in the area has continued intermittently since 1906, when pay was found at 360 ft in Taufkirchen. C. A. F.

865. Pakistan test drilling. Anon. *World Oil*, Jan. 1952, **134** (1), 250.—A test well is being drilled on an anticline at Sui, Dera Bugti, in Baluchistan, after geological and aerial reconnaissance of approx 5000 sq. m. at the southern end of the Sulaiman range. C. A. F.

Geophysics and Geochemical Prospecting

866. Gravity exploration for reefs and other porosity maxima. H. Klaus and J. C. Hughes. *World Oil*, June 1951, **132** (7), 78.—A porosity maximum is defined as a porous rock mass surrounded by less-porous or non-porous rocks, and includes such structures as reefs, lenses, and shoestrings.

In order for a porosity maximum to be measurable, the density boundary must have large relief, porosity changes must be marked, and the total mass must be such that its gravity effects exceed the probable error of the method used. Reefs generally fulfil these requirements.

Variations in bulk density of sediments are due to variations in porosity. Tables are included which show the bulk densities of limestone and dolomite as found in reefs as functions of the porosity, the effect of fluid content on bulk density, density contrasts of limestone and dolomite reefs, and the gravity effects of a vertical cylinder which approximates the shape of many porosity maxima. These charts can be used to estimate either the expected density contrast from known geological conditions or expected positions when the density contrast can be determined.

Nine references are included. C. A. F.

867. Velocity information needed for seismic interpretation. J. W. Daly. *World Oil*, June 1951, **132** (7), 86.—The necessity for improved velocity control in seismic exploration is emphasized, and examples of the relationships between changes in rock types and changing velocity patterns are described.

Velocity data are used for purposes of orientation, correlation, correction, and for interpretative predictions. Isochrons, or equal time lines, and isochronopachs, or lines of equal time intervals, are useful in predicting subsurface conditions.

Since time maps include two variables, distance and velocity, it is possible by means of regional well control to establish the degree to which time changes are related either to stratigraphical intervals or to varying velocity. C. A. F.

868. Continued research improves new exploration tool. A. J. Baxter. *World Petrol.*, July 1951, **22** (7), 40.—The development of the Poulter method of seismic exploration is outlined. In this method a pattern of explosive charges is used above ground, and the energy leaves the points of explosion as shock waves. High-energy seismic waves can be transmitted over a large area and are readily transmitted by the weathered layer.

Extensive tests of the method have been made. C. A. F.

869. Magnetic well logging. R. A. Broding *et al.* *Geophysics*, Jan. 1952, **17** (1), 1–26.—An instrument is described which measures magnetic susceptibility and the total magnetic field in a borehole. By using an alternating-current induction device to measure the susceptibility it is possible to record simultaneously the susceptibility and electrical conduction, and in general there is sufficient contrast in the susceptibility of sediments to enable logs to be used for correlation and tracer studies.

By using this method it has been verified that the magnetic susceptibility of sediments above the basement is so low compared with basic igneous rocks that the sediments have little effect on surface magnetometer results.

Examples of magnetic susceptibility logs are included. C. A. F.

870. Patent. U.S.P. 2,570,659 (1.11.48; 9.10.51). C. H. Fay and R. R. Goodell, assrs to Shell Development Co. A borehole gravity meter operating on the electrical-condenser principle, in which the condenser plates have spherical concave and convex surfaces so that the capacity is not affected by deviations of the gravity meter from the vertical. V. P. P.

Drilling

871. Drilling and producing techniques at Abqaiq. P. C. McConnell. *Oil Gas J.*, 20.12.51, **50** (33), 197.—High permeability of many formations penetrated, and pressure differences between them raise drilling difficulties and up to five strings of casing are common. Drilling without circulation is often resorted to, up to 20,000 b.d. of plain water being pumped down the drill pipe and lost. Cuttings are carried into the highly permeable beds. When high-pressure formations are encountered this method is used with the addition of a "mud cap." This is a stationary column of 80 to 90 lb mud between the drill pipe and the hole floating on the water and reaching to within about 100 ft of the surface, balancing the formation pressure. Normal drilling with mud is employed in the middle, shale, sections of the holes, and when drilling the anhydrite reservoir cap.

The article also summarizes the history and structure of the field. Of sixty-six wells drilled, sixty-one are producers. Field production, from the Arab zone in the Jurassic, is 575,000 b.d., and wells are spaced at least a mile apart. J. C. M. T.

872. Well logging in the Spraberry. W. J. Lytle and R. R. Rieke. *Oil Gas J.*, 13.12.51, **50** (32), 92.—Formation pressures in the Spraberry are very low; to avoid plugging of producing horizons oil-base muds, and even percussion tools in dry holes, are used when drilling in; consequently, normal resistivity logs cannot be run. Instead, an induction logging instrument is used. The instrument has two insulated coils. One is supplied with alternating current, which induces eddy currents in the surrounding rock. These, in turn, induce an alternating e.m.f. in the second coil, which is amplified, rectified, and passed to the surface for recording. The magnitude of the eddy currents in the formation, and hence of the recorded e.m.f., is inversely proportional to the resistivity of the formation. The scale of the record is therefore hyperbolic, so that high ohm values are compressed, low values amplified, a fact of great help in locating water-bearing sand zones.

The induction log is combined with a conventional gamma-ray log, and the combined log can be interpreted by a technique similar to the normal gamma-ray–resistivity log. Specimen logs from the Spraberry are given and discussed, and methods described for obtaining qualitative information on porosity and semi-quantitative information on water saturation. J. C. M. T.

873. Evaluation of rotary drilling lines. J. U. Teague. *Petrol. Engr*, Dec. 1951, **23** (13), B73.—Improved wire-line service can be obtained by: (1) keeping accurate service records for all wire rope; (2) use of longer line and cutting off short lengths at regular intervals; (3) use of large-dia lines; (4) exercising care in handling and use.

Best results are generally obtained by cutting short lengths each time the line accumulates a given number of ton miles. Problems of down-time and transportation of excessive lengths of wire line have also to be considered in determining the number and frequency of cuts made in the lines. C. G. W.

874. Simple and multiple bending of a string of drill pipe. Its influence on the deviation. G. Lugol. *Rev. Inst. franç. Pétrole*, Sept. 1951, **6** (9), 315.—The influence of bent drill pipes on the deviation of a borehole is discussed, and it is shown that for a certain weight on the bit the drill pipe may bend into a simple curve with a possible deviation of more than 1°, whereas a greater weight may cause double bending, which reduces the angle of deviation.

Critical conditions for simple and double bending are outlined, and the mathematics of the problem are described. C. A. F.

875. Crooked holes. B. Schabarum. *Petrol. Engr*, Dec. 1951, **23** (13), B16.—Recent trends towards greater drilling wt and lower rotary speeds have increased the problem of straight-hole drilling.

The use of oversize drill collars, and of stabilizers located above the bit, assists in keeping holes straight.

It is suggested that a study should be made of the problem of crooked hole drilling by the petroleum industry. C. G. W.

876. Power at the bottom of the hole. E. Adams. *Petrol. Engr*, Nov. 1951, **23** (12), B71.—The development of jet rock bits and the currently available commercial jet bits are described.

The value of these bits in clays, shales, conglomerate gypsum, and anhydrite beds is well established.

Field tests are not sufficiently numerous or advanced to determine the applicability of jet bits to hard-rock drilling.

References are appended. C. G. W.

877. New welded full-view mast. J. B. McCormick. *Petrol. Engr*, Dec. 1951, **23** (13), B62.—A combination of welding and bolting on a drilling structure has enabled a mast to be constructed which has strength and stability and is easily broken down into all-welded panels for transport.

With braces and girts located within the legs of an A-frame, an unobstructed view between driller, derrickman, and travelling block is possible.

Details of the design and construction of the mast are given, and the text is illustrated with photographs. C. G. W.

878. Slush pump history and possible developments. R. E. Edwards. *Petrol. Engr*, Dec. 1951, **23** (13), B40.—Past and present slush pumps are described. Improvements in steam pumps need to be made, particularly in the direction of power–wt ratios. The use of torque converter drives and compound operation offer a wide field of application for power pumps.

Of particular interest is the development of higher-speed multiple pumps which may be adapted to slush-pump service. C. G. W.

879. Lost circulation—causes and remedies. H. J. Shumate. *Petrol. Engr*, Nov. 1951, **23** (12), B81.—Lost circulation may be due to: (1) drilling conditions or techniques; (2) conditions inherent in the formation.

Recent work has established that pressure surges of considerable magnitude may be caused by drill-pipe movements, particularly when balled or when running rapidly, pump manipulation, etc. This may result in lost circulation due to breakdown of incompetent formations.

Drilling practices to reduce this condition are described. Methods of locating the point of fluid loss and curative methods for lost circulation are listed.

The principal curative measures are: (1) sealing agents; (2) equalization cementing; (3) diesel-oil-bentonite squeeze (or gypsum cement squeeze); (4) use of emulsion muds to reduce balling; (5) drilling with gases.

The necessity is emphasized of correlating all available information on lost circulation and its remedies. C. G. W.

880. Good mud control saves pipe. H. I. Bussa and F. V. Vick. *Petrol. Engr*, Dec. 1951, **23** (13), B7.—With the present shortage of steel tubular goods it is advantageous to drill as much hole as possible before setting casing. In the ideal case the well should

be established as being a producer before setting a protective casing string. The drilling of long sections of open holes involves very close control of the properties of the drilling mud. In addition to controlling lost circulation, water and gas flows, and possible blow-outs, it is desirable that drilling time should be reduced to a min. The use of emulsion muds has considerably simplified the problem of drilling long sections of open hole.

In guarding against water and gas flows that may lead to blow-outs the following points should be looked for: (1) frothing or gas cutting of mud; (2) excessive decrease in mud wt; (3) increase in salinity; (4) heading or kicking of mud returns; (5) decreased mud pressures; (6) increased mud vol. In addition, the hole must be kept full of mud when pulling pipe, balled-up bits and collars avoided, and blow-out preventers fitted where necessary. Incipient blow-outs may be controlled temporarily by setting a plug of barytes. This is done by circulating a 22 lb/gal (U.S.) slurry of barytes and water until a barytes plug several hundred ft thick is formed. The mud above the plug can then be conditioned and the operations carried out before continuing drilling through the high-pressure zone. C. G. W.

881. Cementing surface casing. B. Barkis. *Petrol. Engr*, Nov. 1951, **23** (12), B54.—A consideration of such factors as the protection of fresh-water formations, the suspension of all other casing strings, and the fact that pressure control is no more effective than the resistance of the cement seal to pressure, emphasizes the importance of efficient cementing for surface casing.

Present practices militating against efficient cementing are: (1) poor-quality mud for drilling surface hole; (2) bonding casing in impermeable shales or hard formations; (3) low slurry velocities in cementing.

The use of scratchers and centralizers to remove the mud cake, the landing of the casing string opposite a porous formation with the shoe set in a shale or impermeable formation, and the use of higher slurry velocities are recommended. Four references. C. G. W.

882. Patents. U.S.P. 2,570,492 (17.2.49; 9.10.51). V. Scarth, assr to Phillips Petroleum Co. Drilling fluid comprising water, a clay, and a water-soluble ethyl sulpho-ethyl cellulose. (In U.S.P. 2,570,947 a mixture of water, a clay, and a water-soluble hydroxy alkyl cellulose is claimed.)

U.S.P. 2,571,093 (27.1.48; 16.10.51). S. E. Temple, assr to Union Oil Co. of California. Aqueous clay suspension containing a water-loss agent (starch, cellulose ethers, Irish moss, alginates, gum tragacanth), a water-soluble salt of a metal more electropositive than iron, and an acidic agent which does not precipitate calcium sufficient to give pH 6·5 to 8·0.

U.S.P. 2,571,247 (6.9.43; 16.10.51). E. A. Huebotter, assr to National Lead Co. Undesirable ions present in gel-containing drilling muds are removed by electrodialysis, and desirable ions of the same sign then added.

U.S.P. 2,569,625 (30.3.50; 2.10.51). M. R. J. Wyllie, assr to Gulf Research and Development Co. Method and apparatus for determining the streaming-potential characteristics of a drilling mud by filtering the mud fluid at various levels in the borehole through its own filter-cake under a pressure differential proportional to the depth in the fluid and measuring the resulting streaming potential and the depth in the fluid.

U.S.P. 2,571,636 (14.10.47; 16.10.51). L. H. Watkins. Apparatus for removing an obstructing metal body from a well bore contains a body of incendiary composition, ignition means, and an oxygen container, the ignition producing sufficient heat to destroy the obstruction. V. P. P.

Production

883. Work-overs in W. Texas. T. W. Kidd. *Petrol. Engr*, Dec. 1951, **23** (13), B55.—The planning is described of work-over operations for wells in one field of this area. Typical operations involved in work-overs are described by examples from well records. C. G. W.

884. Basra's Zubair field. D. M. Duff. *Oil Gas J.*, 13.12.51, **50** (32), 66.—Development by the Basra Petroleum Co. will result in first commercial export of crude in early January. Production, at 11,000 ft, is the deepest in the Persian Gulf, and pressures are the highest. Production from the ten wells is expected to be 25,000 b.d. at first. Another fifteen wells are to be drilled in the Rafidiya sector of the field. Drilling time averages about 150 days per well. J. C. M. T.

885. Pulsation scrubbers. J. R. Bailey. *Petrol. Engr*, Dec. 1951, **23** (13), B50.—The installation of pulsation scrubbers and master flow meters in the delivery lines has very much simplified the problem of metering gas accurately to input wells. Leakages are immediately indicated by comparison of master-meter and individual well-meter readings.

It is also considered that the use of scrubbers on the gas-suction side would improve the operation of the installation. C. G. W.

886. Graphical method of evaluating the performance of oil well sucker rods. J. P. Pedretti. *Petrol. Engr*, Dec. 1951, **23** (13), B30.—In one field where sucker-rod failures are due to corrosion fatigue in has been found that a plot of cumulative rod breaks against cumulative time in service on logarithmic scales gives a straight-line relation.

This has been found of value in evaluating sucker-rod performance and the effect of operating conditions, inhibitors, etc., on rod-break frequency. C. G. W.

887. Notes on well spacing problems. C. W. Tomlinson. *Petrol. Engr*, Nov. 1951, **23** (12), B88.—The present state of hypothesis on the effect of well spacing on ultimate recovery is discussed at length.

The original investigation of well spacing was made by Cutler. The principles derived by Cutler and criticisms of these theories are summarized and discussed. C. G. W.

888. Directional permeability measurements on oil sandstones from various states. W. E. Johnson and J. N. Breston. *Producers' Monthly*, Feb. 1951, **15** (4), 10–19.—Details are given of directional permeability measurements on oil-sand cores from Pennsylvania, New York, Ohio, Kansas, and Oklahoma. These data show that trends of directional permeability exist in some cores from sandstone reservoirs; orientation of such samples enables the geographic direction of max permeability to be determined.

Field tests with tracers have shown that the direction of max flow conforms well with that of max permeability where such exists. Thus it should be possible to effect a more efficient drainage of a reservoir by drilling wells in a diamond-shaped pattern in which the spacing conforms proportionately to the directions of max and min permeability. It is also possible that directional permeability studies can be applied in oil-exploration work because of the relationship between sand characteristics and depositional trends. Five references. R. B. S.

889. Role of clays in the electrical conductivity of the Bradford sand. G. V. Keller. *Producers' Monthly*, Feb. 1951, **15** (4), 23–7.—Among the reservoir properties which effect the resistivity of reservoir sands, the most important are connate-water saturation, tortuosity, and clay content. The clay content of the sand seems to effect its resistivity by increasing the conductivity of the connate water through ion exchanges and by surface conduction over the clay.

According to Archie's Law, $F = \rho_i/\rho_w$, where F is the formation factor, ρ_i is rock resistivity, and ρ_w is water resistivity. It appears that this equation can be applied to sands containing clays, provided that ρ_w is corrected to include the change in conduction caused by ion exchanges and surface conduction over the clay.

Resistivity measurements were made on a large number of cores taken from the Bradford sand, and the results, which are presented graphically, can be used for the correction of resistivity measurements to the values which can be obtained through the use of Archie's Law. The measurements were all made on fully water-saturated samples. Six references. R. B. S.

890. Investigation of resistivity changes during flooding of the Bradford sand. P. Licastro. *Producers' Monthly*, Apr. 1951, **15** (6), 30–3.—Many methods have been proposed to increase the information which can be obtained from electric logs. One

method involves creating an artificially flooded region in the vicinity of the well bore and studying the rate of movement of the flood front with electric logs. To do this two resistivity logs are taken during flooding, separated by a known time interval. The difference between the corrected resistivities is an indication of the rate of movement of the flood front.

Investigations are described in which cores of the Bradford sand were saturated and then flooded by solutions of various salinities with the characteristics of the flood front being observed during infiltration. The total change of resistivity during flooding was not compatible with complete replacement of the connate water by flood water nor with the theory that the rock framework was non-conductive. Insufficient data are available at present to make it possible to derive an equation to predict the resultant resistivity as a function of flooding time, rock properties, and solution resistivity. In addition, the factors which prevent the resistivity from reaching the expected final value are not yet clearly understood. Six references. R. B. S.

891. Selection of pressure for water flooding various reservoirs. J. F. Buckwalter. *Producers' Monthly*, May 1951, **15** (7), 26–31.—Field data are presented which indicate increased oil recoveries at higher flooding pressures. An approach is made towards solving the problems of determining the optimum flooding pressure for new projects. Seventeen references. R. B. S.

892. Use of decline curves in water flood operations. J. F. Buckwalter. *Producers' Monthly*, June 1951, **15** (8), 15–21.—It is shown that oil-production rate versus time curves when plotted on log-log paper may be extrapolated in order to evaluate oil reserves. In addition, the shape of the curves may be used to estimate the permeability distribution in the reservoir or, conversely, oil-production curves may be constructed before water is injected if sufficient core data are available. Nine references. R. B. S.

893. Field results from increased flooding pressures. E. T. Heck and J. C. Vaughn. *Producers' Monthly*, May 1951, **15** (7), 22–5.—Field investigations of the effect of flooding pressure on oil recoveries in the Bradford field are described. The results indicated that higher pressure gradients will result in higher ultimate recoveries of oil to any given water–oil ratio. Two references. R. B. S.

894. Water treatment in water flooding. R. T. Wheeler, A. R. Ellenberger, W. R. Smith, J. R. Lavens, K. P. Huffman, M. E. Austin, J. C. Waterman, J. Cashell, R. W. Amstutz, R. White, F. R. Conley, and A. J. W. Headlee. *Producers' Monthly*, Mar. 1951, **15** (5), 10–31.—Details are given of water-flooding operations and methods of water treatment employed in numerous fields in Arkansas, California, Illinois, Indiana, Kansas, Kentucky, Michigan, New York, Ohio, Oklahoma, Pennsylvania, North, Central, and West Texas, and West Virginia. Nine references. R. B. S.

895. New developments in flood water treatment. J. N. Breston. *Producers' Monthly*, Mar. 1951, **15** (5), 32.—New methods of water treatment for secondary-recovery water-flood projects are discussed. R. B. S.

896. Water flooding of limestones in Illinois and Kentucky. K. P. Huffman. *Producers' Monthly*, Apr. 1951, **15** (6), 17–19.—The performance of some limestone reservoirs under water flooding is discussed. Although many such projects in Illinois and Kentucky have not proved satisfactory, author believes that considerable oil recoveries can be obtained by water flooding, provided more engineering data are made available and a proper engineering analysis is made before the start of the flood. R. B. S.

897. Treatment of produced water in the Bradford field. H. H. Curtin. *Producers' Monthly*, Apr. 1951, **15** (6), 15–16.—A water-treatment plant in use in the Bradford field is briefly described, and an interesting flow diagram of the plant presented. Two references. R. B. S.

898. Increased oil recovery from long core water floods by preliminary gas injection. J. Saxon, Jr., J. N. Breston, and R. M. Macfarlane. *Producers' Monthly*, Jan. 1951, **15** (3), 7–17.—Laboratory experiments on long-consolidated cores indicate that in-

jection of gas ahead of a water flood may lead to increased oil recoveries. In the experiments the core is saturated under pressure with brine and crude oil. The pressure on the core is then released and the core allowed to produce by dissolved gas drive down to equilibrium pressure. The core is then subjected to a brine flood, and the primary and secondary oil recovery is noted. The experiment is then repeated in a similar manner, except that some gas is injected into the core before subjecting it to a brine flood. The primary and secondary oil recovery is again noted.

The apparatus and experimental procedure are described; the cores are mounted in plastic, and the saturation distributions within the core are determined by electrical-conductivity measurements.

The results show that the injection of gas before the start of a water flood tends to increase the oil recovery. This is probably due to an effective gas drive operating ahead of the water flood, to free gas acting as a temporary selective plugging agent (thus preventing channelling in larger pores), and to the substitution of free gas for residual oil. Nine references. R. B. S.

899. Use of carbon dioxide in increasing the recovery of oil. J. W. Martin. *Producers' Monthly*, May 1951, **15** (7), 13–15.—The use of carbonated water for flooding oil sands is discussed. This method enables more oil to be recovered than with ordinary water flood or gas drives. Extremely low residual oil saturations were obtained after flooding some Mid-Continent cores with carbonated water.

It appears that carbon dioxide reacts with some components of crude oil to form polar compounds which affect interfacial forces and enhance displacement. The carbon dioxide also increases the solubility of natural gas in the crude oil. In addition, the presence of carbon dioxide counteracts bacterial growth and prevents the precipitation of certain salts, thus reducing clogging of the sand face in injection wells. R. B. S.

900. Additional oil production through flooding with carbonated water. J. W. Martin. *Producers' Monthly*, July 1951, **15** (9), 18–22.—The treatment of oil sands with a solution of carbon dioxide in water or brine enables greater oil recoveries to be achieved than are possible by ordinary flooding methods. Oil recoveries obtained by this method increase with the degree of carbonation of the water, the temp and the pressure in oil sand, the API gravity of the crude, and the presence of natural gas and wetting agents.

The carbon dioxide reacts with some of the components of crude oil to form polar compounds which lower the surface tension of the oil and modify surface action in the sand itself. Carbon dioxide, since it is soluble in oil and in water, penetrates to the sand surfaces whether they are water wet or oil wet, and by limiting the adsorption of certain surface-active agents enhances their usefulness. In addition, carbon dioxide promotes the solubility of natural gas in crude oil and forms certain complexes with some components of the crude to reduce its visc. R. B. S.

901. Soda water system of conjoint dissolved gas and water drive. F. Squires. *Producers' Monthly*, July 1951, **15** (9), 29–31.—When carbon dioxide and water are co-jointly injected under pressure into an injection well, the carbon dioxide dissolves in the water, and it is actually carbonated water which flows into the oil sand. The carbonated water effects a carbonation of the crude oil in the reservoir in proportion to the solubility of carbon dioxide in water and oil. The solution of carbon dioxide in the crude tends to reduce visc and increase solubility of natural gas in the crude oil. R. B. S.

902. Effects of pressure gradients on oil recovery by water flooding. J. C. Calhoun, Jr. *Producers' Monthly*, May 1951, **15** (7), 18–21.—The effect of pressure gradients on oil recovery by water flooding are often obscured by the effect of other variables. The opinion is expressed that many published data are not reliable unless all possible variables have been eliminated. It is also apparent that any general conclusion will apply differently to oil-wet and water-wet systems. Fourteen references. R. B. S.

903. Use of Calgon in primary production and water flooding. J. P. Kleber. *Producers' Monthly*, Jan. 1951, **15** (3), 18–24.—The action of Calgon in preventing scale formation, in controlling corrosion, and in stabilizing dissolved iron and magnesium is

explained. All of these effects are physical and independent of any chemical constituent of the water and involving no chemical reaction. Scale formation is prevented because the Calgon is adsorbed on the crystal nuclei in the solution in such a way as to prevent crystalline growth. Corrosion prevention is due to the fact that Calgon acts as an adsorptive inhibitor which forms a protective film of molecular dimensions on all metal surfaces in contact with the water at pH values above 5·0, thus isolating them from the oxygen and carbon dioxide present in the water. In addition, Calgon forms a complex with some of the iron and manganese present and disperses the oxides of these metals, thus preventing precipitation for long periods of time.

The factors governing the use of Calgon for treatment of producing wells and in brine-disposal and water-flooding operations are discussed. Six references.

R. B. S.

904. Selective plugging experiments on gas-injection wells in western Pennsylvania. P. T. Bail and C. E. Whieldon, Jr. *Producers' Monthly*, Jan. 1951, **15** (3), 25–35.—The efficiency of recovery by gas injection is effectively reduced by the occurrence of gas channelling through some permeable section of a reservoir sand.

An effective method of selectively plugging the most permeable sections exposed in the walls of an injection well consists of use of a resin emulsion. The application of this method is described, and detailed field data are presented to show its effect on gas-intake rates in numerous wells in Pennsylvania.

These data show that in most of the wells tested the techniques used were evidently not sufficiently selective to prevent by-passing; the reasons for this are briefly discussed. Five references. R. B. S.

905. Case histories of West Virginia gas drives. D. Rogers, Jr. *Producers' Monthly*, July 1951, **15** (9), 11–17.—Production data on thirteen gas-drive projects in West Virginia are presented in graphical form.

The primary production-decline curves are extrapolated to enable the increased recoveries obtainable by gas injection to be computed. Two references. R. B. S.

906. Studies and experiments with paraffin prevention and removal in wells in southeastern Ohio. J. C. Wright. *Producers' Monthly*, Aug. 1951, **15** (10), 14–21.—The causes of paraffin deposition are discussed. Techniques used for removing paraffin deposits, and possible methods of preventing their formation, are reviewed. Eight references. R. B. S.

907. Advent of electrovolatilization. C. M. Davis. *Producers' Monthly*, May 1951, **15** (7), 16–17.—The volatilization of hydrocarbon material contained in narrow coal seams, shale-oil beds, and oil reservoirs, by the passage of an electric current is briefly discussed. R. B. S.

Oilfield Development

908. Exploration 22·3% ahead of 1950 period. Anon. *World Oil*, Jan. 1952, **134** (1), 86.—965 exploratory wells were completed in the U.S.A. in Nov. 1951, of which 168 or 17·4% were producers. Cumulative for the year was 9736 or 22·3% more than in the equivalent period in 1950.

108 new pools were discovered in the U.S.A. in Nov., of which eighty-five were new fields and the remainder new zones.

Tables give the results of exploratory drilling in the U.S.A. in Nov. 1951, and first eleven months, 1951–1950, by districts, and a summary of the results of exploratory drilling. C. A. F.

909. Year's completions set record as predicted. Anon. *World Oil*, Jan. 1952, **134** (1), 34.—41,597 wells were completed in the U.S.A. in the first eleven months of 1951. The total for 1951 is expected to be a record.

53% of the wells were completed as producers, compared with 57% during the same period in 1950.

A table gives well completions in the U.S.A. during Nov. 1951 and first eleven months of 1951. C. A. F.

910. Water flooding the North Burbank field. Anon. *World Petrol.*, Oct. 1951, **22** (11), 48.—36 sq. miles in the North Burbank field in Osage County, Oklahoma, are to be included in a water-flooding project which was initiated in June 1951; it will be the largest secondary-recovery project yet undertaken.

The field was discovered in 1920, and main development was completed by 1927. Peak production was 122,000 b.d. in 1923, and there was rapid decline due to open flow production. Pay is Pennsylvanian Burbank sand, averaging 43 ft in thickness. The original drive was dissolved gas, with some evidence of water encroachment along the northwestern edge.

900,000 acre-ft of the sand have recently been unitized, and a pilot flood was started in 1949. Production from 90 acres was raised from 37 to 404 b.d., and to June 1951, 170,000 brl were recovered from this acreage by flooding.

It has been calc that by flooding of the North Burbank unit field recovery could be raised by 140 million brl. Ultimate water vol required for injection would be 30,000 b.d. C. A. F.

911. Flooding revives Oklahoma pool. A. Gibbon. *World Oil*, Jan. 1952, **134** (1), 160.—The Weber field, Washington County, Oklahoma, was discovered in 1905. Peak production from the Bartlesville was reached in 1909, and decline was rapid. Gas injection was started in 1931, and from 1941 approx 52,000 cu. ft/day were injected through two wells. A third injection well was completed in 1941, and approx 87,000 cu. ft/day were injected from 1941 to 1945. A further well in 1945 increased the injection vol to 127,000 cu. ft/day. The area was developed for water flooding in 1949, and the vol of gas injected was reduced. Water injection was started in 1950, and in 1951 injection rate was approx 7500 b.d. on 180 acres through 56 wells. The water comes from acidized Arbuckle limestone at approx 2500 ft.

Production has been increased by 100% by flooding. C. A. F.

912. Development of Susan Peak field. D. W. Graham. *Petrol. Engr*, Nov. 1951, **23** (12), B7.—Three oil sands have been discovered in this closed structure. Productions are obtained from three zones, the two main zones being porous limestone, the third being a calcareous sandstone which becomes a pure sandstone in parts of the field.

The principal drilling problem has been lost circulation in the Cretaceous limestone, corrected by cementing (in some cases back to the surface) and drilling ahead.

On testing the deepest limestone 362 b.d. of 37° oil at a G.O.R. of 600 : 1. The second limestone gave 120 b.d. of 39° oil at a G.O.R. of 530 : 1. The sandstone zone gave 357 b.d. G.O.R. and gravity not specified. Cross-sections and contour maps are presented. C. G. W.

913. Alberta's greatest year in oil. J. L. Irwin. *World Petrol.*, Apr. 1951, **22** (4), 41–3.—Alberta is the chief source of oil in Canada. 1950 was marked by new discoveries, increased production, the completion of the pipeline from Edmonton to the Great Lakes, and by refinery expansion.

The history of oilfield and refinery development in Alberta is reviewed and future plans outlined. C. A. F.

914. Lloydminster's black oil finding new markets. H. D. Watson. *World Petrol.*, Apr. 1951, **22** (4), 58.—The Lloydminster field in Alberta, 160 miles east of Edmonton, produces from Lower Cretaceous at approx 1850 ft. Wells are pumped, and the crude is a heavy, viscous oil varying from 10° to 19°. Refined products are asphalt, diesel oil, and furnace oil.

There are two refineries at Lloydminster, handling 7500 b.d. and 1500 b.d., and an asphalt plant is being built.

Flooding of the western markets following the Leduc area discoveries caused restricted production at Lloydminster during 1948 and 1949, but the situation has improved recently due to an increase in demand for fuel oil. C. A. F.

915. British Columbia activity. Anon. *World Petrol.*, Oct. 1951, **22** (11), 60.—Discoveries in 1951 in British Columbia have stimulated leasing; exploration is centred in the Peace River and Flathead areas.

Fort St John 1 found oil at 2700 ft and flowed 403,000 cu. ft. gas; 28 miles to the

southeast Pacific ACT Kiskatinaw is drilling below 4500 ft. A deep test to the north is below 10,000 ft.

Drilling in the Queen Charlotte Island area has been abandoned. C. A. F.

916. Venezuela—discoveries exceed production. Anon. *World Petrol.*, Oct. 1951, **22** (11), 41.—Drilling programmes in Venezuela are being accelerated. At the end of 1950 known reserves were estimated at approx 9500 million brl, an increase of approx 500 million brl on the previous year. Oil discovered to date is approx 15,000 million brl, and there are large unexplored areas in the Apure Basin.

Daily average production for 1950 was 1,498,012 brl. C. A. F.

917. New oilfields in Bahia. Anon. *World Petrol.*, Oct. 1951, **22** (11), 63.—A well at Pedras northeast of Salvador, Bahia, Brazil, had an estimated initial production of 300 brl of light oil from approx 900 ft. The well is 48 miles from the Candeias field.

In the Catu field the first well is producing 700 b.d., and in the Paramirim field, discovered in 1950, one of three wells has a potential of 500 b.d. Exploration of both fields continues.

In the D. Joao field there are forty producers averaging 250 b.d/well from approx 2400 ft. C. A. F.

918. The Lacq field. J. E. Pellissier. *World Petrol.*, June 1951, **22** (6), 50.—The Lacq field, 18 miles southwest of Pau in southwestern France, was discovered in 1950. The discovery well pumped 77 b.d., and six subsequent wells are producing approx 4000 b.d.

Pay is Upper Senonian (Campanian) limestone at 1640 to 2300 ft. A constant bottom-hole pressure of 870 p.s.i. at 2033 ft has been found, and the reservoir operates under a water drive.

The crude is naphthenic with sp. gr. of 0·92 and sulphur 3·87%.

Production is shipped by rail to a refinery at Pauillac near Bordeaux. C. A. F.

919. German crude production exceeds million tons. A. M. Stahmer. *World Petrol.*, Mar. 1951, **22** (3), 80.—1950 crude production in Germany was 1,118,400 tons, an average of 23,400 b.d. Emsland produced 45·1%, Hanover 44·4%, Schleswig-Holstein 10%, and Baden 0·5% of the total. C. A. F.

920. 38 million tons German crude reserves. Anon. *World Petrol.*, June 1951, **22** (6), 60.—Estimated German reserves of crude oil are 38,025,000 tons, of which 27·5 million tons are proved and 10·5 million tons probable.

Emsland holds the largest reserve of 18·9 million tons proved and approx 7 million tons probable. Discoveries at Eldingen and Hohne increased the reserves of Hanover by 2 million tons from 1950 to 1951. C. A. F.

921. Soviets extract record yield from Zisterdorf. Anon. *World Oil*, Jan. 1952, **134** (1), 252.—Production from the Zisterdorf fields in Austria is reported as 15,283,520 brl, a record. Pre-war production was 477,600 brl/year.

Ten more wells have been drilled in the Bockfliess area; a life of eight years for the field is estimated.

Current monthly average production is 1,200,000 brl, 27% of which is allotted to Austria. C. A. F.

922. Pakistan Petroleum Inc. prospecting on wide scale. Anon. *World Oil*, Jan. 1952, **134** (1), 252.—Core holes have been drilled near Sylhet in Pakistan as part of an extensive exploratory programme in East and West Pakistan. The holes are being drilled to 4000 ft. The work is estimated to last six months. C. A. F.

923. Borneo production mounts. Anon. *World Oil*, June 1951, **132** (7), 256.—Principal source of oil in British Borneo is the Seria field in Brunei. Peak production from the field is 100,000 b.d., or approx 36,145,000 brl/year.

The field was discovered in 1929 after detailed exploration; to 1940 approx 150 wells had been drilled, some offshore, and since 1945 there has been rapid development; wells now total approx 270.

Tertiary sediments in the area are approx 30,000 ft thick, lying in the East Indian geosyncline, and they have been affected by Alpine Plio-Miocene movements. Favourable oil structures are gentle folds, often asymmetrical and locally thrusted. Pays, which are clayey sands between 1500 and 4000 ft, are Miocene and Pliocene, and the oil is believed to be of Miocene age.

The refinery at Lutong in Sarawak was rebuilt after the war, and has since been enlarged. Throughput is 38,000 b.d. C. A. F.

924. New oil search in Sarawak jungle. Anon. *World Petrol.*, July 1951, **22** (7), 48.—Two wildcats are being drilled in Sarawak; at Subis, 12 miles inland, and at Bulak Setap. Extensive geological and geophysical surveys have been made in the area.

In Brunei the Seria field is producing at 5,000,000 tons/year; six times the pre-war rate. C. A. F.

925. The search for oil in Australia. E. Bee. *World Petrol.*, Sept. 1951, **22** (10), 60.—No significant oilfields have been discovered in Australia since gas was found in 1897, but exploration has not been abandoned, and large areas remain untested. Revision of oil legislation in the early 1930s encouraged exploration in various parts of the continent by major companies.

Government agencies and oil companies are now extensively mapping areas in Northwest Australia, and a dry well has recently been drilled at Morella in Queensland. Plans have been made to explore the Long-reach area in Queensland, and test wells have recently been drilled for natural gas in the Lake Frome area in South Australia.

In the Northwest Basin, where experts consider oil possibilities to be good, detailed surveys have been made since 1948, and a seismic survey and a test well are planned. C. A. F.

Transport and Storage

926. Modern communications. H. A. Rhodes. *Pipe Line News*, July 1951, **23** (7), 39–40.—The design and operation of a micro-wave communication system, of particular importance in pipeline construction and maintenance, is discussed. F. M.

927. 1952 seen as another active pipeline year. P. Reed. *Oil Gas J.*, 28.1.52, **50** (38), 250.—Twelve tables show principle domestic (U.S.A.) and foreign crude-oil and products, pipelines projects planned, under-way, and completed. G. A. C.

928. Natural gas pipeline construction at record levels. P. Kayser. *Pipe Line News*, Oct. 1951, **23** (10), 33–4.—A review of the expansion in pipeline construction from 1942 to 1951, with an analysis of recent U.S. legislation affecting the natural-gas industry. F. M.

929. Great Lakes Pipe Line Co. completing large expansion programme. Anon. *Pipe Line News*, Dec. 1951, **23** (12), 17–22.—A survey, with map, of progress in the Great Lakes Pipe Line Co. expansion project involving new lines from Cushing, Oklahoma, to Sioux Falls in South Dakota, Iowa City in Iowa, and Minneapolis in Minnesota. F. M.

930. Texas Eastern makes fine progress. Anon. *Pipe Line News*, Oct. 1951, **23** (10), 30–2.—A brief account of the expansion programme of Texas Eastern Transmission Corp., 791 miles of 30-inch line are being laid between Kosciusko (Miss.) to Connellsville, Pa., and this includes numerous river crossings. Brief details of compressors, storage areas, and gathering systems are given. F. M.

931. Cold weather pipelining. T. S. Johnston. *Pipe Line News*, Nov. 1951, **23** (11), 27–9.—A brief account of some of the problems encountered in laying the Interprovincial Pipeline from Redwater (Alberta) to Superior (Wis.), a total distance of 1126 miles, with particular reference to frozen-ground conditions. F. M.

932. Products line spans Mexican isthmus. B. Mascanzoni. *World Petrol.*, 1952, **23** (1), 40–1.—Distribution of indigenous pet products to West Mexican coast was previously by rail and thence by tanker to Pacific ports, supplemented by direct imports. Pipeline (10¾ inches) has been laid over difficult 245-km terrain between Minatitlan and Salina Cruz. Operation is controlled from single pumping station on east coast equipped with two Wilson-Snyder reciprocating pumps (one operating) of 15,000 b.d. each. Crude will eventually be pumped through at rate of 30,000 b.d. when a half-way station will be installed. Investment was 25 million pesos, and transport savings will amount to 1 million pesos monthly. E. B.

933. The Trans-Arabian Pipe Line Co. system. Anon. *Pipe Line News*, July 1951, **23** (7), 25–38.—The construction of the Trans-Arabian Pipe Line Co.'s (Tapline) pipeline from Qaisumah in northeastern Saudi Arabia to Sidon, 723·5 miles northwest in Lebanon is described and illustrated. South of Qaisumah the Aramco (Arabian American Oil Co.) pipeline extends 314 miles to gather oil from the Abqaiq fields. Tapline is constructed of 30- to 31-inch O.D. pipe and with four pumping-stations, and is capable of handling 300,000 b.d. Difficulties encountered from the original planning to the final commissioning are described, together with details of several new techniques. F. M.

934. Design features of "Steepest Inch" pipeline. Anon. *Oil Gas J.*, 11.2.52, **50** (40), 103.—The Tacagna products line between Caracas and Catia de la Mar is only 10 miles long, but is one of the world's steepest in operation.

There is only one pump station, and special precautions have been taken as regards safety. A highest pressure of 2000 p.s.i. has been allowed for. G. A. C.

935. Automatic gauging, sampling, and testing equipment. F. H. Warren. *Pipe Line News*, Nov. 1951, **23** (11), 31–2.—A review of recent developments in automatic gauging, sampling, and testing equipment. F. M.

936. Developments in products pipeline technology. J. R. Shipley. *Pipe Line News*, Dec. 1951, **23** (12), 31–5.—A review of recent developments in fire-fighting systems, pipeline filters, meter installations, cutting of batches, and electrical controls in product pipeline systems. F. M.

937. Steel for pipelines. G. A. Wilson. *Pipe Line News*, Dec. 1951, **23** (12), 28–30.—A discussion of existing steel controls. F. M.

938. Modern pipe welding practices. F. C. Fantz. *Petrol. Engr*, Oct. 1950, **22** (11), C38–42.—Reinforcement of welded branch connexions and butt joints are considered. For the former, the following methods are available: (1) use of saddle type reinforcement; (2) application of welded reinforcing ring; (3) addition of supplementary deposits of metal to the filler weld; and (4) use of welding tee. Where the branch connexion is one-quarter the size of the header, or less, little reinforcement is necessary, and (3) can be used. Butt-welds are reinforced by welding sleeves. Welding procedures are mentioned, submerged arc-welding, both semi-automatic and automatic, is discussed fully, and the importance of accurate preparation of the grooves for automatic welding is stressed. Description of aluminium welding with an A.C. tungsten arc shielded with argon gas is included. E. S. L.

939. Pipeline scraper traps for natural gas transmission lines. P. Reed. *Oil Gas J.*, 7.1.52, **50** (35), 72.—The economic value of "on-stream" scraping and its use are discussed. Many combinations of fittings can be used, but the operator should know exactly what is in the line. The horizontal type of scraper trap is best for general service. Launching and receiving traps should be one size larger than pipeline. By-passes should be fitted with drains. Pipe openings to the trap should be safe for scraper operations.

Old lines contain obstructions to scraper operation, such as mitre bends, welding ells, and reduced-area venturi-type plug valves, and scraping, if any, was done in sections. G. A. C.

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940. Pressure effects of elevation on gas pipelines. J. W. J. Bercher. *Pipe Line News*, Nov. 1951, **23** (11), 20.—The following formula is advanced to evaluate the effect of elevation on pipeline pressures.

$$\log P_L = \log P_H + 0{\cdot}000015652GZE$$

where P_L = pressure at lowest point, p.s.i.a.;
P_H = pressure at highest point, p.s.i.a.;
G = sp. gr. (air = 1);
Z = compressibility factor at P_0;
E = difference in elevation in ft. F. M.

941. M.V. Esso, Abingdon. Anon. *Fluid Handling*, 1952 (24), 2–4.—The new design of 500-ton-capacity barges for Thames operation is detailed. Dimensions, speed, engines, tanks, pipes, pumps, and safety precautions are described. D. H.

942. Positive displacement meters for liquid hydrocarbons. E. W. Jacobson. *Pipe Line News*, Oct. 1951, **23** (10), 39–43.—The design of positive-displacement meters is discussed and illustrated by detailed drawings of several commercially available meters. F. M.

943. Patent. B.P. 659,005 (30.12.48; 17.10.51). "Shell" Refining and Marketing Co. Ltd. Pallet for elevating and stacking drums, barrels, etc. V. P. P.

Refinery Operations

Refineries and Auxiliary Refinery Plant

944. Monsanto plant at Newport, IV. Anon. *Fluid Handling*, 1952 (24), 5–7.—After treatment with lime slurry to fixed pH and small quantities of soda ash the effluent is settled before pumping away to the river. Specifications for pumps, motors, and gear are given.

The HCl-absorption plant is glass and vitreosil throughout. D. H.

945. Deep Rock builds today for tomorrow. W. T. Ziegenhain. *Petrol. Engr*, Dec. 1950, **22** (13), C29–30.—A description of the improvements in the refinery at Cushing, Oklahoma, in particular the vis-breaker and catalytic cracker is given. Topped crude is fed to the former and produces gas-oil charging stock for the latter. A flow diagram of each is given. F. S. L.

946. Automatic blending at Fawley refinery. G. Weber. *Oil Gas J.*, 7.1.52, **50** (35), 66.—The Esso Petroleum Co.'s Fawley refinery has four completely instrumented continuous blending systems for finished motor fuel, diesel oil, light fuel, and bunker fuel. A diagrammatic flow chart shows initial operations of the refinery, and another illustrates the gasoline-blending plant. The dye-addition facilities and additive systems are described, together with the diesel and fuel-blending units.

These units permit Fawley to operate on a minimum of intermediate or process tankage capacity. G. A. C.

947. In-line products blending cuts costs, improves quality. P. Gordon. *Oil Gas J.*, 21.1.52, **50** (37), 86.—Equipment for in-line blending of light products at Shell's Montreal refinery is described.

Features include speed in blending, accuracy, reduction of high T.E.L. concentration hazards, uniform product quality, blending tanks eliminated, and no vapour losses.

Diagrams show flow sheet for in-line remotely controlled gasoline blending, control scheme for automatic addition of T.E.L. inhibitor and dye, and management of control loop for each gasoline component.

Equipment is operated by one foreman and two assistants during daytime. G. A. C.

948. The new Cit-Con lubricating oil refinery. M. Hackler. *Scientific Lubrication*, July 1951, **3** (6), 16–21.—The new Cit-Con refinery at Lake Charles, Louisiana, processes

reduced crudes to produce 6000 lb/day of finished 95VI oils in five grades. The installation, comprising vacuum towers, furfural unit, dewaxing, and storage plant, is described in some detail. J. G. H.

949. Complete East Chicago refinery expansion. A. L. Foster. *Petrol. Engr*, Aug. 1950, **22** (9), C36.—Modernization of the refinery is described, the main items being a fluid catalytic cracking unit with a charge of 14,760 b.d. and a delayed coking unit (thermal) producing 600 tons of petroleum coke/day. E. S. L.

950. Refinery expansion in The Netherlands. V. S. Swaminathan. *Petrol. Engr*, Oct. 1950, **22** (11), C34.—A description of the expansion, completed and proposed, at the Bataafsche refinery at Rotterdam-Pernis, and other development plans in the Netherlands, is given. E. S. L.

951. Ultra modern Canadian lubricant plant. H. C. Plummer. *Petrol. Engr*, Nov. 1951, **23** (12), C5–10.—A new $2 million lubricating-oil and grease-blending plant is now operating at the Montreal East refinery of Canadian Oil Co. Ltd., using the latest processing methods combined with mechanical devices to give automatic control of plant operation. Violent agitation is used to obtain homogenized products so that dispersion of additives and blending materials is more complete. Greases are conditioned and tempered by pumping at high velocity through the close-set spinning disks of a colloid mill in order to reduce the tendency to thin when introduced to bearings. A de-aerating device is incorporated to improve both appearance and performance. Drums are reconditioned on a mechanical-conveyor system, where they are de-dented, stripped and buffed, washed and rinsed, both outside and inside, using chemical and detergent solutions. Foreign matter is removed from the inside of the drums by "drum-chainer," which introduces a cleaning solution and several lengths of special chain with sharp-edged links and rotates the drums at high speed. The slightest leaks are discovered by applying air pressure to the drums while rotating in a water-bath with a strong light in the depths of the bath. The fully mechanized oil-canning operation, as described, is capable of filling 18,000 Imp. qt/hr. E. K. J.

952. Ultra-modern ideas used in Cartharge plant. A. L. Foster. *Petrol. Engr*, Oct. 1950, **22** (11), C45–8.—A description of this Texas gasoline plant handling 220 million cu. ft. wet field gas per day is given. The propane and butane products are commercially pure hydrocarbons. E. S. L.

953. Modern refinery in Western Venezuela goes on stream. H. C. Plummer. *Petrol. Engr*, Oct. 1950, **22** (11), C16.—A description of the Cardon plant on the Paraquana Peninsula which consists of distillation units (atmospheric and vacuum) with capacity of 38,000 b.d. of crude; two thermal crackers, each with capacity of 11,000 b.d. of crude; a reformer; and phosphate, soda, acid, and doctor treating units. Utilities and accommodation are also discussed, and a flow sheet given. E. S. L.

954. LPG production at Marcus Hook refinery. H. F. Thomson. *Petrol. Engr*, Aug. 1950, **22** (9), C54.—A description, with flow diagram and compositions, of a unit with a capacity of 1100 b.s.d. of liquefied propane gas, is given. E. S. L.

955. "Most economical" gas plant. E. D. Soltes. *Petrol. Engr*, Nov. 1950, **22** (12), C34–7.—A gasoline plant of modern, coventional design, at Mineral Wells, Texas, to handle from 7 to 14 million s. cu. ft. of wet gas per day at pressures from 75 to 200 p.s.i.g., giving 80% butane and 75% propane, is described. It is quoted as an example of how a gasoline plant can be built and operated with a min of capital expenditure. E. S. L.

956. Design of gasoline plants. Pt 3. Piping layout. O. L. Lewis. *Petrol. Engr*, Jan. 1952, **24** (1), C28–36.—The first two parts dealt with plant and equipment layouts. The piping layout must be carried out on the basis of experience so that the pipework fits in with the rest of the design. There are four methods of arranging the piping: (1) underground; (2) in trenches; (3) on piers, just above ground level; and (4) overhead on stanchions. Factors affecting the choice of elevation are detailed. Pipes

in different directions should be at different elevations to facilitate crossing, and buried lines should run at established depths to prevent confusion with other services. The recommended allowance of space for expansion is 50% above normal requirement. Allowance must also be made for thermal expansion of pipes in operation, and flexibility may be obtained most economically by absorbing the expansion in simple bends of the pipe. Special problems associated with piping for pumps, compressors, exchangers, and turbines are discussed. Vents and drains must be provided at all high and low points of the line respectively. E. K. J.

957. Processes for natural gasoline plants and associated systems. A. S. Glendening and C. F. Sanderson. *Petrol. Engr*, May 1950, **22** (5), C54.—A discussion of gasoline plants which produce such varied products as natural gasoline, butanes, propane, ethane, *iso*butane, *iso*pentane, and, when distillate is processed, motor fuel, kerosine, naphtha, diesel oil, and solvents. The plants are classified in two groups by the method used to liquefy the production. The majority of plants do this by oil absorption, but others use refrigeration and compression. Oil-absorption plants are described incorporating rich-oil stabilizers and a two-stage absorption oil-distillation system to control the methane and ethane. An absorber is described with side chilling to enable a lower-mol.-wt. oil for absorption, thus having less oil circulation. Under the second classification vapour rectification and refrigeration–compression systems are described. Process heating and cooling, sulphide and mercaptan treating and dehydration, are also discussed. Line diagrams of the processes are given. E. S. L.

958. Pumoridge pump index. Anon. *Fluid Handling*, 1952 (24), 24.—(See Abs. 2327—1951, 456—1952.) Ajax centrifugal; Candy M. Minor; Carruthers Vertical Duplex; Pneu; Stuart centrifugal. D. H.

959. Standardization of refinery pump parts. W. H. Gilbert. *Petrol. Engr*, May 1950, **22** (5), C62.—A method is presented to standardize pump parts to cover all pumps in the plant, thus eliminating any long shut-down due to pump failure while keeping the stock of spares down to a min. The method is developed for centrifugal pumps, but can be extended to reciprocating or rotary ones. E. S. L.

960. Design of large pumping installations for low and medium heads. Pt II. G. A. Wauchope and H. P. Humphreys. *Fluid Handling*, 1952 (24), 9–12.—(See Abs. 458.) Characteristic properties of centrifugal and axial pumps with variation of head and quantity are compared. Methods of speed control, priming, and surge prevention are enumerated. D. H.

961. Keep your pumps on stream. L. J. Dawson. *Petrol. Engr*, Nov. 1950, **22** (12), C13.—The importance of keeping pumps working is emphasized, and the following pumps described: double-suction, for general purposes; double suction with water-cooled extra-deep stuffing-boxes and smothering glands, for temp up to 800° F; overhung design process pump with one stuffing-box or mechanical seal, also modified to include open-type impeller for slurry service; multi-stage horizontal and vertical pumps for high pressures. In choosing pumps the correct design and materials of construction must be selected carefully. The design and application of stuffing-boxes, the selection of sleeve materials, and use of mechanical seals are discussed. Maintenance of pumps is "preventative" and "reconditioning." In the former, packing and lubrication require particular attention. With regard to the latter, how to tell when an overhaul is required, and the correct procedure for it, are discussed. E. S. L.

962. Stuffing boxes for centrifugal pumps. V. Lobanoff. *Petrol. Engr*, Mar. 1950, **22** (3), C33.—Limitations of mechanical seals are indicated in explaining the continued use of stuffing-boxes. The importance of selecting correct packing material, of keeping the temp and pressure on the packing as low as possible, and of keeping abrasives, corrosives, and volatile liquids away from the packing is stressed. Illustrations and descriptions of the following stuffing-boxes are included: (1) one for low pressure and temp and clean liquids, including soft packing and a lantern ring for liquid sealing or grease lubrication; (2) one used in processing industries for medium pressures and temp up to 800° F, including metallic packing, a lantern ring and a water-jacket;

(3) one for handling high-temp, high-pressure liquids while the packing operates under low temp and pressure, a long throttle bushing and two lantern rings are included; (4) one to handle pressures up to 5000 p.s.i.g., incorporating a long breakdown bushing and a leak-off chamber; (5) one for handling boiler-feed water up to 350° F incorporating a water-cooled breakdown bushing. A chart gives leakage loss per inch of sleeve dia through a throttle or breakdown bushing for varied pressure drops and diametral clearances based on the visc being that of water. E. S. L.

963. Figuring air receiver pump-up time. T. G. Hicks. *Petrol. Engr*, Mar. 1950, **22** (3), C27.—A chart is given enabling pump-up time for an air receiver in a compressed-air system to be read off knowing the volume of receiver, compressor-piston displacement per minute, "cut-in" pressure, and "cut-out" pressure. The chart is based on an assumed average volumetric efficiency of the compressor of 80%. Correction for atmospheric pressure is illustrated. E. S. L.

964. Electromagnetic mercury pumps for circulating gases. J. E. Paddington. *Canad. J. Tech.*, 1951, **29**, 311.—Designs for two gas-circulating pumps are described. In one type bulbs are attached to each end of a U-tube and mercury is made to flow alternately from one bulb to the other, thus forming a liquid system. It may be used either as a double- or single-action pump. In the other design, which is also a modified U-tube, mercury is circulated continuously in one direction, gas being entrained between slugs of mercury as it flows externally from one arm of the U to the other to complete the cycle. In both models circulation speeds of 600 to 800 cc of gas per min can be obtained, and in both the mercury is pumped electromagnetically. A. D.

965. Water-cooling towers. Pt 1. Principles and applications. H. E. Degler. *Petrol. Engr*, Mar. 1950, **22** (3), C29–30; (4), C15; (6), C25.—An elementary introduction to cooling towers, with definitions of operating terms. Examples of calculation of cooling range are given.

Construction and application of spray ponds and water-cooling towers are discussed in Pt 2. The following towers are considered; natural draught, forced draught, and induced draught (counter-flow, horizontal flow, and cross-flow). Finned-tube dry-cooling units with both forced and induced draught are also discussed. Detailed diagrams of induced-draught counter-flow and cross-flow towers, and photographs and diagrams of the others are included.

In Pt 3 the following points are discussed: (1) water treatment to prevent scale on heat exchangers, to prevent and control algæ formation, and to control delignification of the wood of a tower; (2) starting-up procedure with necessary inspection to be carried out; (3) operation, both normal and when ice formation is likely (ice prevention and removal is considered)—daily inspection is recommended; (4) mechanical and structural maintenance with a recommended maintenance-inspection schedule; (5) shutting-down procedure. E. S. L.

966. Cooling tower efficiency. Anon. *Petrol. Engr*, Aug. 1950, **22** (9), C48.—A chart is given for rapid determination of the efficiency. E. S. L.

967. Here's how to solve your oil-field-engine cooling-water problems. L. C. Case. *Oil Gas J.*, 21.1.52, **50** (37), 95.—A method using sodium tannate for water conditioning without field testing control for small and relatively isolated plants operating on low make-up water rates is described.

Tables show average analysis of cooling-water supply and of water from circulating systems. G. A. C.

968. Heat-exchanger maintenance. J. H. Fitzpatrick. *Oil Gas J.*, 28.1.52, **50** (38), 372; *Petrol. Engr*, Oct. 1951, **23** (11), C42.—The application of four principal methods of cleaning heat-exchangers and thus ensuring max efficiency is described.

Type of deposit, time required for job, and cost influence cleaning method. Deposits can be classified as hard, porous or loose, and the different ways of cleaning exchangers include chemical, wet sand-blast, dry sand-blast, and mechanical. G. A. C.

969. Heat transfer. G. T. Skapendas. *Industr. Engng Chem.*, 1952, **44** (1), 75–8.—Review of eighty-nine references. E. J. C.

970. Heat transfer coefficients for vapours condensing on horizontal tubes. R. E. Peck and W. A. Reddie. *Industr. Engng Chem.*, 1951, **43** (12), 2926–31.—A correlation has been developed which corrects much of the discrepancy found in results calculated by the Nusselt equation. A theoretical analysis is presented, and new and older data correlated in a straight-line plot. E. J. C.

971. A new approach to design for radiant heat transfer in process work. R. D. Reed. *Petrol. Engr*, Aug. 1950, **22** (9), C7.—In establishing reaction characteristics of a furnace, the following are considered: (1) radiation from flame burst of burners; (2) radiation from hot refractory planes; and (3) radiation from CO_2 and H_2O content in flue gases. The abilities of flames made by two fuels to radiate vary as the square of the ratio of their relative H/C ratios by wt. Radiation from yellow flames may be from 19 to 225% greater than from blue flames, and it is pointed out that yellow flames do not indicate inefficient burning unless caused by insufficient air. Consideration of the heat transferred and heat lost in flue gases in a furnace is found incompatible with the idea of furnace gases drifting slowly towards the stack. An explanation is found in the type and magnitude of gas circulation in the furnace (in one case the complete furnace volume of gas circulated by the tubes on the wall every 2·4 min). This is upheld by instances cited, and the necessity for allowing for circulation in design is emphasized. E. S. L.

972. A study of mass transfer rates from the solids to the gas phase. A. C. Plewes and J. Klassen. *Canad. J. Tech.*, 1951, **29**, 322.—Five pure solids were vaporized in turbulent air streams, and the results obtained indicate that the evaporation processes may be correlated by the Sherwood–Gilliland relationship for the vaporization of liquids from moving films into turbulent air streams.

$$\frac{d}{x} = 0{\cdot}023\ Re^{0{\cdot}83}\,Sc^{0{\cdot}44}$$

The work indicates that the mechanism for mass transfer in solid–gas systems is analogous to that for existing liquid–solid systems, and the results offer a convenient method for estimating rates of sublimation and condensation in solid–gas systems. A. D.

973. Temperature gradients in turbulent gas streams—methods and apparatus for flow between parallel plates. W. H. Corcoran, F. Page, Jr., W. G. Schlinger, and B. H. Sage. *Industr. Engng Chem.*, 1952, **44** (2), 410–19. F. Page, Jr., W. H. Corcoran, W. G. Schlinger, and B. H. Sage. *Industr. Engng Chem.*, 1952, **44** (2), 419–23. F. Page, Jr., W. G. Schlinger, D. K. Breaux, and B. H. Sage. *Industr. Engng Chem.*, 1952, **44** (2), 424–30.—Detailed description is given of the apparatus and technique employed in measuring temp and velocity distribution for air flow between horizontal parallel plates, and for obtaining point values of eddy conductivity and visc in uniform flow between parallel plates.

First article deals mainly with velocity distribution, the second with temp profiles, and the third with eddy conductivity and visc. Considerable data are given in tabulated and graphical form. E. J. C.

974. Gas mixing in beds of fluidized solids. E. R. Gilliland and E. A. Mason. *Industr. Engng Chem.*, 1952, **44** (1), 218–24.—Apparatus, procedure, and results obtained in studying gas-mixing in fluidized beds are described. E. J. C.

975. Thermodynamics of natural gas compression. G. L. Farrer. *Petrol. Engr*, Nov. 1950, **22** (12), C23.—Basic equations are developed from the first and second laws of thermodynamics, then integrated for isothermal work and non-flow adiabatic work of compression. Single- and multi-stage compression are considered and examples given. For the latter the min work is attained when the pressure ratio is the same in each stage, so most compressors are designed to give equal work in each stage. The use of charts (plotting the thermodynamic properties of the gases to be compressed) for non-ideal gases is shown. The ratios of specific heats for some gases are tabulated. Seven references. E. S. L.

976. Performance of thermal poly transeconomizers. J. H. Smith. *Petrol. Engr*, Aug. 1950, **22** (9), C18.—An investigation into the performance of transeconomizers in a thermal polymerization unit showing the effect of the addition of naphtha to the feed (consisting of light ends recovered from stabilization of pressure gasoline and raw casinghead), and of quenching (to counteract fouling). The naphtha increased the coking rate, thus reducing heat transfer, and the quenching counteracted the fouling to some extent, but produced local coking and increased the pressure drop. In general, coking in process heating or cooling is most severe where vapour-to-liquid transition is just commencing or the opposite nearing completion. E. S. L.

977. Analysis of thermal insulation problems in respect to refrigerated equipment. J. F. Stone. *Petrol. Engr*, May 1950, **22** (5), C37 (*cf. Petrol. Engr*, **22** (1), C11).—To solve a thermal-insulation problem it is necessary to know: (*a*) the primary purpose of insulation (*e.g.*, for most economical operation or for accurate process control, etc.); (*b*) condition of operation (*e.g.*, equipment, outdoors or in buildings, temp conditions steady or cyclic, etc.); (*c*) the anticipated life of the plant or process under consideration; (*d*) designed temperature of all items; (*e*) allowable limits of heat loss or entry if any; (*f*) average, max, and min air temp to be expected, and associated relative humidities; (*g*) the rate of flow and characteristics of the fluid where end temp is a factor. The commonly used equations for heat transfer through insulation are given, together with the Modified McMillan equation for the most economical insulation thickness. It is noted that on refrigerated equipment the theoretical economic thickness is rarely usable. Sources of necessary data, etc., required for insulation analysis are given, and three worked examples illustrating the use of the equations are included. Derivation of the McMillan equation is given in an appendix. Three references. E. S. L.

978. Wire spotting technique for insulation. R. L. Davies. *Petrol. Engr*, Nov. 1950, **22** (12), C21–2.—When a flat or curved metal surface cannot be punctured or banded, insulation is attached by spot welding lengths of galvanized wire to it. A table of recommended min thicknesses of blanket insulation is given. E. S. L.

979. The refiner's notebook. Anon. *Oil Gas J.*, 4.2.52, **50** (39), 89.—No. 108 in this series gives a nomogram for rapidly estimating make-up vol and blowndown, and an example with solution is given. G. A. C.

980. Material and heat balance calculations. G. L. Farrer. *Petrol. Engr*, Dec. 1950, **22** (13), C20.—The importance of carrying out proper material and heat balances is stressed, in order to obtain actual loss of heat and material in a process, check on operating conditions, and obtain information on the effects of process variables on product quality and product-recovery rates. The physical data for these balances are discussed, and sources for obtaining them given. Example calculations are given on: a boiler; two distillation columns; a partial condenser; and a thermal cracking unit. E. S. L.

981. Specific heat ratio in compression calculations. W. C. Edmister. *Petrol. Engr*, Dec. 1950, **22** (13), C13.—The computation of the ratio of specific heats is discussed, and charts required are given. E. S. L.

982. The refiners' notebook. J. A. Pelleterre. *Oil Gas J.*, 7.1.52, **50** (25), 93; 14.1.52, **50** (36), 125.—No. 104 in this series describes orifice turbine governors, their operation and characteristics. Three types are dealt with, viz., variable speed, hydro mechanical, and hydraulic, all wide range. No. 105 gives a summary on turbine governors, and describes the ideal governor, listing its advantages. Good governor design is based on the theory of cascaded controls. G. A. C.

983. Spiral wound gaskets on flanged joints. W. W. Boyd. *Refiner*, 1951, **30** (12), 120–3.—The spiral-wound gasket has been designed for use at temp up to 1800° F and pressures up to joint designs. The gasket comprises a strip of metal with a V crimp wound into a spiral and contains a filler between adjacent strips. Ferrous and non-ferrous metal and metal and non-metallic fillers can be used. The advantages of this

type of gasket are low seating stress, low bolt stress, and resiliency. Gaskets for standard types of joint are described. A. R. H.

984. Expansion joint insulating technique. M. K. Bonner. *Petrol. Engr*, Jan. 1952, **24** (1), C41.—Details of construction are given for a new application of mineral-wool pipe insulation for expansion joints on gas and air ducts which minimizes surface cracks and hot spots and eliminates special fabrication. E. K. J.

985. Banded block technique. R. L. Davies. *Petrol. Engr*, Dec. 1950, **22** (13), C40–1.—Where metal surfaces which cannot be punctured but can be banded need to be insulated, it can be accomplished by banding mineral-wool block insulation to the equipment with metal bands or wires, so that only the blocks touch the surface. Successive steps for carrying this out are given, together with recommended min thicknesses of blocks of board insulation. E. S. L.

986. Supports for vertical pressure vessels. Pt IV. F. E. Wolosewick. *Refiner*, 1951, **30** (12), 151–3.—The stresses set up in skirt supports for vertical pressure vessels due to thermal expansion are analysed mathematically and equations developed for the estimation of the flexural stress and radial shear. A. R. H.

987. Short cuts in pilot plant engineering. J. C. Rearick. *Petrol. Engr*, Oct. 1951, **23** (11), C44–52.—The specialized techniques required for the design and construction of pilot-plant equipments are discussed. The progress of a pilot-plant project is traced from the process design to fabrication. Reference is made to standardization of equipment such as piping, electrical heaters, control panel, and instruments, and the resulting advantages are outlined. Engineering costs must be kept within proper proportion of the total cost without affecting plant performance, and figures of 10 to 15% are quoted for this proportion. E. K. J.

988. Pilot plant design. B. M. Wedner, W. A. Horne, and T. P. Joyce. *Petrol. Engr*, Nov. 1951, **23** (12), C11–16. (*ASME Mtng, Tulsa, Sept.* 1951.)—The usefulness of bench-scale pilot plants depends upon safe design from temp and pressure standpoint, precision of instrumentation, flexibility of process design, and the ability of the pilot unit to perform in prototype the functions of the full-scale unit. Safe design for high temp and pressures depends on following existing pressure-vessel codes and using good engineering judgment in selection of materials and stress limits to which they may be subjected. E. K. J.

989. Chemical cleaning. V. E. Bowes. *Petrol. Engr*, May 1950, **22** (5), C20.—Chemical methods for cleaning refining equipment in general and heat exchangers in particular are considered. Two methods employed are circulation of chemical cleaning materials through shell and tube sides or immersing a pulled tube bundle in a tank of cleaning material. Classifications of equipment used (which can be fabricated by the refinery itself) are: (1) permanent or temporary, to clean banks *in situ*; (2) mobile, which is rolled into place when required; (3) stationary, used for immersion method. Reasons for cleaning heat exchangers are given, and regular cleaning is recommended. A suggested method of recording the cleaning history of a heat exchanger is included. Knowledge of the kinds of deposits to be removed is required, visual, and in many cases, chemical examination being necessary. Most typical deposits have been listed, and knowledge of the type of cleaning material required is available. Cleaning and descaling solutions, alkaline, acidic, or solvent, should: (1) be safe for personnel to use; (2) be non-volatile and safe on equipment; (3) require a min of work for best results; (4) provide job-wide economy; (5) work quickly with min of equipment. The cleaning of pulled tube bundle sand heat exchangers *in situ* (with diagrams of equipment required) is discussed, the necessity of control by titration being emphasized for the latter. E. S. L.

990. Chemical cleaning of process side equipment. C. H. Groom. *Petrol. Engr*, May 1950, **22** (5), C48.—Process side deposits encountered in refinery equipment are usually organic in nature, although mixtures of organic and inorganic (usually iron and copper oxides and sulphides and other metallic salts) deposits are also met. The organic

deposit may be anything from a light volatile fluid to a highly polymerized material or decomposed coke-like material apparently untouched by the common solvents. The deposits are usually classified roughly by breaking down into oil soluble, oil insoluble, and inorganic. Typical deposits found in different types of refinery process equipment are listed. Factors to be considered in removing these deposits are: (1) deposit to be removed; (2) solvent to be used; (3) unit to be cleaned. The removal is usually effected by a combination of chemical and mechanical means, the chemical means being the use of strong oxidizing solvents, and the mechanical means being the use of high-velocity circulation to remove the disintegrated deposits. The introduction of the solvent into the centre of tube bundles to obtain contact with all deposits is discussed. Nine references. E. S. L.

991. Extraction of dust and mist. J. A. Campbell. *Petrol. Engr*, Mar. 1950, **22** (3), C17.—The development is discussed of a demister, originally required to remove crude oil mist from natural gas before entering a compression plant in which natural gasoline was extracted by compression and refrigeration. Design is based on the fact that agglomeration of the mist into a film is simple, but it is difficult to prevent the film being blown back into the gas stream. The higher the surface tension of the film the easier it is to prevent this. A description of two Mist-D-Fiers is given, one incorporating screens (to give the agglomeration) with metal baffles behind them to collect the film and prevent re-entrainment, and another with improved baffles, thus eliminating screens. Also described is a combined dust scrubber and Mist-D-Fier in which oil is used to scrub the dust and then the oil mist is removed as above. The oil is contacted with the gas in syphon tubes which are baffled to obtain intimate contact. Photographs showing a Lucite model both static and working illustrate the action of the Mist-D-Fier. E. S. L.

992. Economics of waste heat recovery. L. D. Stewart. *Petrol. Engr*, Aug. 1950, **22** (9), C26.—A review of methods of waste-heat recovery, with examples to emphasize the monetary gain possible. Five references. E. S. L.

993. Fluid dynamics. M. Leva and M. Weintraub. *Industr. Engng Chem.*, 1952, **44** (1), 68–75.—Review covering two hundred and fifty-one references. E. J. C.

994. Ion exchange. R. Kunin. *Industr. Engng Chem.*, 1952, **44** (1), 79–84.—A review, including water softening, of four hundred and sixty-six references. E. J. C.

995. Materials handling. R. L. Speaker. *Industr. Engng Chem.*, 1952, **44** (1), 85–8.—Review of twenty-three references. E. J. C.

996. Mixing. J. H. Rushton. *Industr. Engng Chem.*, 1952, **44** (1), 88–91.—Review of seventeen references. E. J. C.

Distillation

997. Pennzoil carries propane fractionation to advanced stage. G. Weber. *Oil Gas J.*, 21.1.52, **50** (37), 78.—The operation of a deresining unit allowing propane fractionation of reduced crude stocks to be carried to a new advanced stage at Rouseville, Pa., by Pennzoil Co., is described.

In addition to the conventional extraction tower used in modern propane deasphalting units, a secondary propane fractionator and two settling vessels which split the high-visc resins separated from the raw cylinder stock charge are also provided. The raw deresining unit has a capacity for processing 1370 b.s.d. of raw charge.

A chart shows flow scheme of the propane deresining and resin fractionation unit, and a table depicts average deresining operation. G. A. C.

998. High temperature distillation. T. J. Walsh. *Industr. Engng Chem.*, 1952, **44** (1), 45–9.—A review covering part of 1950 and 1951. One hundred and fifteen references. E. J. C.

999. Extractive distillation. S. R. M. Ellis. *Birmingham Univ. Chem. Engr*, 1951, **2**, 44–8.—A summary of the theoretical background of extractive distillation. Includes sections on vapour–liquid equilibrium relationships, the selection of the solvent, and the applications of extractive distillation. A list of the systems under investigation in the Department of Chemical Engineering, University of Birmingham, is included. S. B.

1000. High efficiency corrugated gauze packing for controlled flow distillation. A. J. Hayter. *Industr. Chem.*, 1952, **28**, 59–64.—Efficiency of corrugated gauze packing in 1-inch- and 2-inch-dia columns for dist of benzene/carbon tetrachloride mixtures was investigated. Gauzes used ranged from 38 to 72 mesh, width of corrugation from $\frac{5}{32}$ to $\frac{9}{32}$ inches, apexes 60°. Each gauze rested directly on, with corrugations at 90° to, gauze immediately below. Unsealing of apertures in coarse-mesh gauzes could occur at high vapour velocities, causing reduced efficiency and increase in H.E.T.P. from 1 to 5 inches. Difficulty overcome by use of double gauzes. With this type of packing no change in fractionating efficiency was effected by variation in packed height; column could also operate inclined at 10° to vertical without loss of fractionation. Hold-up and pressure-drop figures are reported. Use of this type column, 2 inches dia 46 ft high, equivalent to 400 theoretical plates has been applied to separation of hydrogen and oxygen isotopes of water. A. C.

1001. Distillation in a multi-tube wetted-wall column. E. E. Lindsey, J. M. Kieffer, and C. L. Huffine. *Industr. Engng Chem.*, 1952, **44** (1), 225–31. Apparatus, procedure, and results are reported for work carried out during batch distillation of methanol–water and trichloroethylene–toluene in a multi-tube wetted-wall column. H.T.U. and H.E.T.P. values were high, the pressure drop low, although on the basis of pressure drop per unit transfer unit it is no better than for packed columns. Data are tabulated and plotted.

The column may find use in vacuum distillation, where the overhead product has a high boiling point. E. J. C.

1002. Rapid calculation of plate number and reflux ratio in batch distillation. F. J. Zuiderweg. *Chem. Engng Sci.*, 1951, **1** (1), 8–17.—An extension of the Bowman–Cichelli method for determining plate requirements and min reflux is given with a relation between these min requirements and the number of plates and reflux ratio to be used in practice. This method takes into account the effect of hold-up in the case that the concentrations in the column are in equilibrium with the bottom concentrations. Alignment charts are given which simplify the method of calculation. Experimental data are given to justify the theoretical method. These data show the method to be applicable to systems with more than two components if certain conditions are fulfilled. It is shown that concentrations in the column not in equilibrium with the bottom concentration give an actual reflux ratio lower than the calculated. In some cases the actual reflux ratio is lower than the min reflux ratio. C. J. P.

1003. Patents. U.S.P. 2,570,205 (12.3.48; 9.10.51). C. S. Carlson and P. V. Smith, assrs to Standard Oil Development Co. Separating mixtures of ethyl and propyl alcohol by extractive distillation with sulpholane.

U.S.P. 2,570,066 (26.8.48; 2.10.51). M. R. Morrow and J. W. Smalling, assrs to Standard Oil Development Co. Separation of naphthenes from paraffins by extractive distillation with tetramethylbenzene. V. P. P.

Absorption and Adsorption

1004. Four-Horizon Dollarhide's casing-head gas processed in new gasoline plant. J. R. McChesney. *Oil Gas J.*, 11.2.52, **50** (40), 123.—The compression–adsorption type unit operated by Pure Oil Co. in Andrews County, Texas, is described. H_2S and CO_2 are removed by monoethanolamine contractors, and the gas is dehydrated. Methane-free product is treated for removal of C_2, C_3, and C_4 fractions.

Product-treating facilities include a caustic wash and Perco treaters.

Storage of approx seven days' production of each of the three plant products is available. G. A. C.

1005. Snyder gasoline plant fed by 850 wells. A. L. Foster. *Petrol. Engr*, Oct. 1951, **23** (11), C22–32.—The collaborative natural-gasoline plant in the Kelly–Snyder area of Texas is handling about 60,000,000 cu. ft/day of raw gas, and the average liquid hydrocarbons recovered is 6·5 gal/1000 cu. ft. Details are given of the construction and operation of the liquid hydrocarbon recovery plant which produces about 400,000 g.p.d. of liquid hydrocarbons as: (1) debutanized gasoline; (2) normal butane; (3) *iso*butane; and (4) propane. Natural gas is compressed to 500 p.s.i.g. and the liquids removed by oil in the absorber, the lower section of which acts as a de-ethanizer. The component hydrocarbons are separated by three-column fractionation of the vapours obtained by stripping the rich oil. Two systems of gas gathering are employed in parallel which operate at 200 p.s.i.g. and 15 p.s.i.g. High-pressure gas is used to move condensate formed in the low-pressure line by automatic collection of drips at low points of the line and which are forced back into the low-pressure line at a high point nearer the plant. Considerable steel saving is obtained by eliminating a third condensate line. E. K. J.

1006. Absorption and humidification. R. L. Pigford. *Industr. Engng Chem.*, 1952, **44** (1), 25–30.—A review covering 97 references. E. J. C.

1007. Adsorption. B. L. Harris. *Industr. Engng Chem.*, 1952, **44** (1), 30–8.—This review of 1950 published literature includes industrial applications such as hypersorption processes. Three hundred and forty-four references are appended. E. J. C.

1008. Natural-gas dehydration using triethylene glycol. L. L. Laurence. *Oil Gas J.*, 7.1.52, **50** (35), 76.—Water in gas-transmission lines reduces gas-carrying capacity of the line, forms hydrates which restrict or stop gas flow, and if acid gases are present, results in a corrosive condition.

Operating data on a gas-dehydrating unit, with triethylene glucol dessicant, are given. Such a plant can efficiently operate at flow rates and 10 to 100% of rated capacity, has a low initial cost, and low dessicant loss. A table gives cost data, and a typical flow diagram is shown. G. A. C.

1009. Technical aspects of glycol-amine gas treating. A. L. Kohl and C. L. Blohm. *Petrol. Engr*, June 1950, **22** (6), C37.—Presentation of data of tests on seven high-pressure plants purifying (to less than 0·25 grain H_2S per cu. ft.) and dehydrating 418 million s.c.f/day of gas using monoethanolamine and diethylene glycol. Typical flow diagram of a plant is given, the gas treating and stripping being accomplished in bubble-cap columns. The object of the tests conducted was to ascertain the min circulation of amino solution necessary to produce the required purity at design gas-flow rate. The testing and analytic procedures are described, and the reactions in the contactor, in which hydrogen sulphide, carbon dioxide, and water vapour are absorbed, are considered and the gas compositions and temp in this unit are plotted for varying inlet-gas composition. When handling an extremely acidic gas, a cool overhead is more likely. The performance of the still and reboiler in the stripping stage giving a lean solution with H_2S content of less than 15 grains/gal was investigated, and a plot of composition and temp in this stage is given. The better stripping obtained with glycol-amine solutions is believed to be due to the high temp in the still and reboiler. Operating data are tabulated. Eleven references. E. S. L.

1010. Gas plants for catalytic cracking units. F. E. Gilmore and R. D. Bauer. *Petrol. Engr*, Nov. 1951, **23** (12), C26–36.—A survey of methods is presented for raising propane and butane recoveries by increasing the absorption factor through alteration of the values of the effective liquid and vapour rates and of the equilibrium constant. The effect of these changes on the operating processes is discussed, and examples of improvements that have been obtained are given. A modern gas plant, designed to recover 90% of C_3s, uses a de-ethanizing absorber with a low-mol.-wt. primary lean oil and adequate sponge-oil facilities, and eliminates all recycle gas streams from the fractionating equipment. E. K. J.

1011. Absorption isotherms for pure hydrocarbons. R. A. Koble and T. E. Corrigan. *Industr. Engng Chem.*, 1952, **44** (2), 383–7.—Brief discussion is given on theoretical

aspects of adsorption isotherms. Plotted data are given for the adsorption of methane, ethane, ethylene, propane, and propylene by active carbon at temp ranging between 100° and 400° F. E. J. C.

1012. Rich oil rectification. E. G. Ragatz. *Refiner*, 1951, **30** (12), 143–8 (*California Natural Gasoline Ass., Los Angeles, Oct.* 1951); *Oil Gas J.*, 14.1.52, **50** (36), 107–11.—Compared with the conventional process schemes, the use of rich-oil rectification offers the advantages of higher percentage absorption recovery of propane with less heat consumption. With this scheme it will usually be necessary to employ an auxiliary trimming control for correlating the unit's operation with 24-hr cyclic changes in plant intake quality. Of the various auxiliary controls available, direct measurement and control of the volume of vapours introduced into the base of the rectifier offers the most promise. (Author's Abstract.) A. R. H.

1013. Patents. U.S.P. 2,571,936 (6.3.48; 16.10.51). J. A. Patterson and J. P. Morgan, assrs to Standard Oil Development Co. Separation of a C_{6-7} mixture containing *cyclo*hexane *a*, paraffins *b*, olefins *c*, and aromatics *d*, by selectively adsorbing *a*, *c*, and *d* on carbon, and then desorbing the carbon by heating first to *ca* 300° F to liberate *a*, then to a higher temp to liberate *c* and to a still higher temp > 550° F to remove *d*.

U.S.P. 2,571,329 (13.12.46; 16.10.51). C. H. O. Berg, assr to Union Oil Co. of California. A normally gaseous mixture containing components of differing critical temp (C.T.s) is mixed with a recycle stream containing components of intermediate C.T.s and fractionated to separate overhead components of lower and intermediate C.T.s, from which the latter are removed by adsorption on a granular solid and then recycled. V. P. P.

Solvent Extraction and Dewaxing

1014. Solvent extraction. R. E. Treybal. *Industr. Engng Chem.*, 1952, **44** (1), 53–63.—A review covering 377 references. E. J. C.

1015. Rotary filters added to propane dewaxing plant. J. C. Albright. *Petrol. Engr*, Mar. 1950, **22** (3), C37.—A detailed description is given of a propane dewaxing plant, incorporating Oliver rotary filters, handling a charge of 1900 b.d. from a Duo-sol solvent refining plant and producing 1425 b.d. of stock which is vacuum distilled to give definite SAE grades. Raffinates of 75 and 65% oil yield are handled well. Details of feed and products are given. E. S. L.

1016. Laboratory extraction apparatus. H. L. Lochte and W. G. Meinschein. *Petrol. Engr*, Mar. 1950, **22** (3), C41–2.—A description is given of a simple and efficient laboratory extraction apparatus employing sixteen screw-cap quart bottles with a fractional-h.p. motor to rotate it. Any number of stages up to sixteen can be used without repassage through the bottles, and extraction with reflux can be carried out. A four-stage separation of acids by fractional neutralization and liberation is described fully. Other laboratory extractors are mentioned. E. S. L.

1017. Laboratory liquid–liquid extraction column. J. F. Short and G. H. Twigg. *Industr. Engng Chem.*, 1951, **43** (12), 2932–3.—A compact laboratory extraction column is described consisting of a vertical tube with a concentric rotor forming an annular space for countercurrent flow of liquids. The height equivalent to a theoretical stage is stated to be 0·6 to 4 inches, depending on system and operation. By using different rotor dia and different rotor speeds the column can be made very adaptable. E. J. C.

1018. Performance of a packed liquid–liquid extraction column under controlled agitation. G. E. Feick and H. M. Anderson. *Industr. Engng Chem.*, 1952, **44** (2), 404–9.—An apparatus is described consisting of a packed column in which agitation could be imparted to the liquids by a reinforced neoprene diaphragm at the base of the column. The diaphragm was actuated by a rod-and-cam arrangement driven through variable-pitch pulleys. Performance data are given for the extraction of benzoic acid from toluene by water using ½-inch McMahon saddles and ¾-inch Raschig rings, and for the extraction of acetic acid from toluene with water using ½-inch McMahon

saddles. Results indicate a number of advantages over stationary columns for systems which do not show tendencies to form stable emulsions. For instance, extraction coefficients were large, H.T.U. values low, and flow fluctuations can be readily handled. E. J. C.

1019. Patents. U.S.P. 2,572,583 (21.12.48; 23.10.51). H. R. Antle, assr to Phillips Petroleum Co. Di(β-cyanoethyl)amine is used as a first selective solvent in liquid-phase extraction of hydrocarbon mixtures.

U.S.P. 2,571,752 (28.5.48; 16.10.51). W. V. Oberbaugh, assr to Texas Co. In separating a mixture of a low-visc oil and wax by crystallization of wax and filtration in presence of a solvent, addition of a wax-free lub oil of higher visc reduces crystal size so that wax cake is of lower oil content.

U.S.P. 2,570,044 (23.12.48; 2.10.51). B. C. Benedict and W. N. Axe, assr to Phillips Petroleum Co. In propane fractionation of crude lub.-oil stock, plugging of the apparatus with asphalt is prevented by withdrawing propane containing dissolved oil from the top of the zone, separating the oil from the propane and extracting it with phenol, a mixture of aromatic and naphthenic oils being separated from the extract and recycled. An asphalt-free, oil-rich liquid phase is withdrawn from the bottom of the zone.

U.S.P. 2,571,919 (2.12.48; 16.10.51). C. E. Morrell, assr to Standard Oil Development Co. Process for concentrating a lower fatty acid present in a dilute aq solution containing higher-boiling carboxylic acids by extraction with combinations of low- and high-boiling solvents. V. P. P.

Cracking

1020. First "packaged" T.C.C. unit now on stream. W. O. Jacobs. *Oil Gas J.*, 21.1.52, **50** (37), 92.—This unit now in operation in Artesia, N.M., plant of New Mexico Asphalt & Refining Co., includes feed-preparation, catalytic cracking section, fractionation, gas plant, and catalytic polymerization, and has a fresh-feed capacity of 6000 b.s.d. of gas oil.

Unit has max flexibility, and is expressly designed for small refineries where catalytic cracking facilities of moderate cost are required to keep pace with production of higher-octane gasolines. A flow sheet is provided. G. A. C.

1021. How Sohio made first complete internal inspection of 240-ft T.C.C. cat lift line. C. I. Ball. *Oil Gas J.*, 11.2.52, **50** (40), 106.—A bosun's chair was used by the Standard Oil Co., Ohio, for inspection of the catalyst line. An "Audigage" was employed to determine metal thicknesses. A telephone was used for communication. Trip up and down pipe took 20 min without inspection stops. G. A. C.

1022. Heat transfer and pressure drops in fixed beds of spherical and cylindrical solids. Pt 1. J. M. Campbell and R. L. Huntington. *Refiner*, 1951, **30** (12), 127–33.—The literature is reviewed, and data are presented on the pressure drop in fixed beds of spherical and cylindrical particles. Experimental work is reported on 2-inch, 4-inch, and 6-inch columns packed with silica–alumina, hydrated alumina, aluminium, tabular alumina, and glass commercial packings, and the results correlated by the equation

$$\frac{\Delta P}{L} = \frac{C\mu^2}{g\rho D_p^3 \phi}\left(\frac{D_p . G}{\mu}\right)^{1.85} . \frac{1-f_1}{f_1^3}$$

where P = pressure drop in inches of water;
L = depth of bed, ft;
μ = gas visc;
G = mass velocity;
D_p = equivalent dia;
f_1 = fraction voids;
C = constant;
ϕ = area–volume shape factor
g = acceleration due to gravity
ρ = density of gas

Values of C are given for the packings studied. A. R. H.

1023. T.C.C. cracking of Rocky Mountain crudes. A. L. Foster. *Petrol. Engr*, Nov. 1950, **22** (12), C7–12. A description is given of Socony's refinery at Casper, Wyoming, which converts a mixture of nine crudes, some sweet, some sour, into more than 50% motor gasoline. The plant is conventional, except that in the Thermofor catalytic cracking unit the feed to the reactor is both vapour and liquid. The ability to handle liquid feed depends entirely upon the amount of heat supplied, but the effluent must be vaporized to allow separation from the catalyst. Improvement in gasoline, distillate fuel oils, polymer products yield, etc., is claimed to be the effect of the addition of liquid feed. A flow diagram and details of a fourteen-day check run are given.
E. S. L.

1024. New design features in catalytic-cracker. H. K. Wheeler. *Petrol. Engr*, Oct. 1951, **23** (10), C5–10.—The 7000 b.d. fluid catalytic cracking unit at El Dorado, Arkansas, is completely heat balanced in operation, as all heat required to complete the reaction is supplied by combustion of the coke so that neither recycle catalyst coolers nor preheat furnace are required. Emphasis has been placed on: (1) simplified design of units, to reduce installation and operating cost, and (2) open layout, to facilitate inspection and maintenance. The reactor of the catalyst plant surmounts the regenerator to eliminate an elevator. Transfer of catalyst back to reactor is by means of air pressure, and fresh catalyst is introduced by vacuum from a steam ejector. The highest operating level is kept to a min elevation, and most of the process control is possible from the lowest levels. Other details of operation and mechanical construction of the plant are described in adequate manner. E. K. J.

1025. Repair and maintenance of cat cracking equipment. W. F. Dougherty. *Petrol. Engr*, May 1950, **22** (5), C33.—The maintenance of a Thermofor catalytic cracking plant with an operating capacity of 3500 b.d. reactor charge by thirty-four men with ten extra during a turn-around is discussed. Maintenance is broken into two groups: (*a*) normal maintenance, and (*b*) that required during a turn-around. (*a*) Consists of maintenance of pumps, engine and compressor, instruments, exchangers, condensers, turbines, electrical equipment, steam system, piping, etc., and emergency repairs, catalyst loading, and fires removal. The monthly cost is $1550. (*b*) Maintenance is discussed a month before turn-around, and a work schedule made out. After shut-down a thorough inspection ascertains whether this need be expanded. A breakdown of the three turn-arounds carried out on this plant (first two at half-yearly intervals and the third a year later) is given, together with details of conditions of, and work carried out on, the reactor, the kiln, the catalyst chopper valves, the hot catalyst elevator, the synthetic crude fractionator, and piping. Protective helmets are worn by the maintenance crew throughout. E. S. L.

1026. New synthetic catalyst plant to supply 450,000 b.d. cracking capacity. G. L. Glespen. *Refiner*, 1951, **30** (12), 134–6.—A brief description is given of a plant completed during 1951 by American Cyanamide at Michigan City for the manufacture of microspheroidal silica–alumina cracking catalysts. A. R. H.

1027. Houdriforming for aromatics. H. Heinemann, J. W. Schall, and D. H. Stevenson. *Petrol. Engr*, Oct. 1951, **23** (11), C40–2.—The Houdry catalytic reforming process can be applied to the production of aromatic concentrates and high-octane motor gasoline from petroleum naphthas. Pilot-plant data are given on the Houdriforming of: (1) pure compounds; (2) naphthas containing aromatic formers; and (3) straight-run naphthas. It is found that aromatics content of product increases with severity of conditions to a limiting value, then the proportion of *iso*paraffins increases. High yields of aromatics are obtained up to 95% of the equilibrium conversion of naphthenes to aromatics, and yields of high-octane motor gasoline up to 86 vol-% of charge are obtained with the process. E. K. J.

1028. Fundamentals of fluid hydroforming. E. V. Murphree. *Refiner*, 1951, **30** (12), 97–101. *Proc. Third World Petrol. Congr*, 1951, **4**, 215–24.—Fluid hydroforming provides an economical means for reforming low-octane naphthas. Fixed-bed processes operating at 900° to 1000° F and 200 to 300 p.s.i.g. with a molybdena catalyst gave 2·5% yield improvement over the thermal reforming and olefin polymerization process

on a 10-lb R.V.P. base at 90 Research O.N. Temp drops of 250° F were experienced in fixed-bed adiabatic processes, necessitating high preheat temp, which gave rise to thermal cracking. In a pilot-plant 1·2% C_2s in feed to reactor bed due to pre-cracking reduced yield from 90 to 87·5%. With an isothermal process, as approached in fluid hydroforming, gasoline yields were improved by 5·1 and 8·6%, with O.N.s of 85 and 95 respectively. Pre-cracking is practically eliminated with fluid operation. Gasoline yields by thermal reforming plus polymerization, improved fixed-bed hydroforming, and fluid hydroforming are compared. 5·5 vol-% advantage is achieved with fluid hydroforming over the fixed-bed process for 95 O.N. 10-lb R.V.P. gasoline, carbon formation being 0·6 to 1·0% higher, a molybdena–alumina catalyst being used. Capital investments and running cost are lower for the fluid process, giving a total saving of about 40 c/brl. It is advantageous to produce a small quantity of high-quality blending stock rather than to improve the total naphtha stock. A. R. H.

1029. The application of fluid hydroforming. H. G. McGrath. *Refiner*, 1951, **30** (12), 102–8. (*Amer. Inst. Chem. Engrs, South Texas Section, Galveston, Oct.* 1951.)—Data are presented on the operation of a 3-b.d. fluid hydroforming plant. The effects of temp, pressure, tail-gas recycle, precatalytic reforming, and catalyst age have been studied. The reactions involved are discussed. A molybdena–alumina catalyst was used, after six weeks' operation the 0 to 20μ fraction only increased from 3 to 12% indicating good attrition resistance. Yield of debutanized gasoline at 82 O.N. (motor) increased from 62% at 900 cu. ft. gas recycle to about 75% at 4500 cu. ft/brl. Pre-cracking reduced the yield at a given O.N. Yield decreases with increase in temp, with O.N. of product, and with increase in pressure. Fluid hydroforming is compared with competitive processes; better yields and higher O.N.s are indicated.
A. R. H.

1030. Patents. U.S.P. 2,572,664 (29.12.47; 23.10.51). S. P. Robinson, assr to Phillips Petroleum Co. Preparation of acetylene using a pebble heater, in which a normally gaseous hydrocarbon (A) preheated to 1700° to 2300° F is mixed with superheated steam produced by combustion in the pebble heater of a gas containing $\leq$84% hydrogen in insufficient oxygen, so that (A) is heated to $>$2450° F for $<$0·02 sec, the product being rapidly quenched. A mixture containing $\leq$10% acetylene and $>$5% oxides of carbon is produced, from which acetylene is separated and a mixture containing $\leq$84% hydrogen and carbon oxides is recycled to the pebble heater.

U.S.P. 2,572,338 (28.7.50; 23.10.51). K. T. Hartwig and T. B. Haufe, assrs to Universal Oil Products Co. Cracking reactor provided with two concentric inlet conduits for gaseous reactants, the inner conduit having a flared end section extending to the reactor wall, the apical portion of the flared section having a number of orifices, and a conical deflector concentric within the flared section forming with it a mixing annulus of gradually increasing volume.

U.S.P. 2,571,342 (18.2.47; 9.10.51). J. A. Crowley, assr to Socony-Vacuum Oil Co., Inc. Vaporized feed to a cracking process for gasoline production is supplied by partially cracking a high-boiling liquid-hydrocarbon fraction by contacting with a heat-absorptive material consisting of capsules containing a fusible substance capable of releasing latent heat at a temp below that at which excessive conversion of the hydrocarbon to gas and coke would occur, and above that at which the vaporized hydrocarbon fraction formed will condense.

U.S.P. 2,570,607 (18.11.48; 9.10.51). R. B. Smith, assr to Sinclair Refining Co. Reduced crude oil stock, heated in liquid phase to *ca* 900° F/$>$1 atm to effect incipient cracking, is passed to a small flash zone to remove fixed gases and then flashed in an enlarged vacuum zone at 750° to 850° F/150 to 350 mm Hg, removing vaporized gas-oil overhead and unvaporized bottoms from the vacuum zone.

U.S.P. 2,570,067 (16.6.47; 2.10.51). J. W. Myers, assr to Phillips Petroleum Co. Hydrocarbon conversion with a vanadia- and/or molybdena-containing catalyst at 1050° to 1250° F which is regenerated by contacting with a reducing atm at 700° to 1025° F, then burning off the carbonaceous material and again heating in a reducing atm at 1050° to 1250° F.

U.S.P. 2,570,058 (23.7.49; 2.10.51). E. A. Hunter, assr to Standard Oil Development Co. Preparation of magnesia gels by reacting Mg with a $C_{<4}$ alkanol in presence of $CHCl_3$ or CCl_4 and a catalytic Hg compound to form the Mg alcoholate, which is then hydrolysed.

U.S.P. 2,570,063 (12.4.49; 2.10.51). C. N. Kimberlin, assr to Standard Oil Development Co. Agglomeration of microspheroidal particles during drying is prevented by pre-treatment with water at 150° to 212° F for 5 to 24 hr. V. P. P.

Polymerization

1031. The emulsion polymerization of isoprene II. W. L. Reynolds, A. L. Johnson, and R. H. Clark. *Canad. J. Tech.*, 1951, **29**, 343.—This work was undertaken to attempt to increase the mol. wt. of the polyisoprene resulting from cumene hydroperoxide initiation while at the same time keeping the gel content low and also to test various mercaptans, disulphides, and diozoethers or initiating agents. The yields obtained with these reagents were compared with the rates of thermal decomposition in a few cases where this was possible.

The effect of the types of compounds named above upon the polymerization was investigated, and in the case of certain of the ethers the half-decomposition period was measured. A. D.

1032. The emulsion polymerization of isoprene III.—The measurement of the amount of vinyl groups. N. E. Phillips and R. H. Clark. *Canad. J. Tech.*, 1951, **29**, 349.—Describes a new and improved method of calculating the amount of vinyl groups in a polymer from its rate of reaction with perbenzoic acid. This has been used to compare three types of emulsion isoprene with natural rubber. A. D.

1033. Patents. U.S.P. 2,570,032 (23.6.48; 2.10.51). R. L. Heinrich, assr to Standard Oil Development Co. Preparation of feed stock to be used for catalytic polymerization, in which a naphtha containing olefins and oxygenated organic compounds is contacted with H_2S at 40° to 250° F to form a higher-boiling reaction product which is removed.

U.S.P. 2,572,724 (21.5.49; 23.10.51). G. P. Hinds, W. K. Meerbott, and G. J. Reno, assrs to Shell Development Co. In polymerization of propylene to tetramer, the effluent from the reaction zone is separated into: (*a*) a normally gaseous fraction comprising propylene; (*b*) a C_{4-7} hydrocarbon fraction; (*c*) a C_{8-10} hydrocarbon fraction; and (*d*) a tetramer fraction. (*a*) and (*c*) are recycled to the polymerization zone and (*b*) is polymerized separately in absence of propylene to the tetramer.

U.S.P. 2,571,354 (22.1.49; 16.10.51). C. M. Fontana, assr to Socony-Vacuum Oil Co., Inc. Polymerization of monoalkylethylenes in presence of a solution of $AlBr_3$ in an inert solvent and a promoter.

U.S.P. 2,569,688 (12.5.47; 2.10.51). H. F. Park, assr to Monsanto Chemical Co. Copolymerizing styrene and isoprene in aqueous solution of sodium salts of mahogany acids containing a minor amount of dodecyl mercaptan in presence of $K_2S_2O_8$.

U.S.P. 2,569,448–9 (7.7.45; 2.10.51). J. N. Borglin and P. A. Ray, assrs to Hercules Powder Co. Alkali metal salts of dehydroabietic acid are used as emulsifying agent in emulsion polymerization of: (*a*) isoprene with a mono-olefinic compound containing a $CH_2{=}C<$ group; (*b*) styrene.

U.S.P. 2,569,447 (17.6.44; 2.10.51). J. N. Borglin and P. A. Ray, assrs to Hercules Powder Co. Aqueous emulsion polymerization of a mixture of a conjugated butadiene hydrocarbon and a mono-olefinic compound containing a $CH_2{=}C<$ group with a peroxide catalyst in presence of alkali-metal salts of hydroabietic acid.

U.S.P. 2,569,480–1 (22.3.46; 2.10.51). E. J. Lorand, assr to Hercules Powder Co. (*a*) Emulsion polymerization, (*b*) homogeneous polymerization, of compounds containing a $CH_2{=}C<$ group in presence of an aryl(dialkyl)methyl hydroperoxide in which each alkyl has $\geqslant C_4$.

U.S.P. 2,569,462 (22.3.46; 2.10.51). A. E. Drake, assr to Hercules Powder Co. Emulsion polymerization of compounds containing a $CH_2{=}C<$ group in presence of a water-soluble persulphate and an aryl(dialkyl)methyl hydroperoxide in which alkyl has >4 C.

U.S.P. 2,572,028 (3.2.50; 23.10.51). M. Hunt, assr to E.I. du Pont de Nemours and Co. Polymerization initiation with a water-soluble hydrazo disulphonate and a compound containing positive halogen.

U.S.P. 2,570,601 (13.11.50; 9.10.51). L. Schmerling, assr to Universal Oil Products Co. Production of resins by heating 3 : 4-epoxy-1-butene and a vinyl compound at 150° to 350° C.

U.S.P. 2,569,524 (16.6.49; 2.10.51). J. M. Hamilton, assr to E.I. du Pont de Nemours & Co. $CClF{=}CF_2$ alone or mixed with $CF_2{=}CF_2$ is polymerized at 20° to 60° C/$<$60 p.s.i. in presence of an aq catalyst system containing Ag, alkali bisulphite, and persulphate. V. P. P.

Alkylation

1034. Patents. U.S.P. 2,572,701 (20.9.42; 23.10.51). B. B. Corson and W. M. Kutz, assrs to Koppers Co., Inc. Preparation of cumene by continuously flowing a mixture *A* of benzene and propylene in molar ratio 4 : 1 into 80 to 96% aq H_2SO_4 at 20° to 80° C and adding *A* to the cumene—containing reaction mixture at the hourly rate of 1 part of *A* to 2·2 parts by wt of acid present.

U.S.P. 2,570,574 (22.4.49; 9.10.51). C. B. Linn, assr to Universal Oil Products Co. 2 : 3-Dimethylalkane is produced by reacting *iso*butane with a $C_{>4}$ alkene—1 in presence of HF at below −10° C.

U.S.P. 2,572,019 (30.6.50; 23.10.51). F. S. Fawcett and B. W. Howk, assrs to E.I. du Pont de Nemours & Co. Alkylation of aromatic compounds with olefins in presence of a molybdite of a metal whose ions are soluble in aq NH_4OH. V. P. P.

Isomerization

1035. Vapour-phase butane isomerizer operation. C. L. Persyn. *Oil Gas J.*, 11.2.52, **50** (40), 111.—A new procedure in operating the Shell-type unit at the Avon, Calif., refinery of Tide Water Associated Oil Co. is described, resulting in longer catalyst life, greater on-stream time, and increased throughput. Catalyst used is a material consisting of about 18% aluminium chloride impregnated on a carrier.

The new technique is that reactor is first filled with an " original charge " consisting of plain " Porocel " carried in bottom two-thirds of tubes, then the top third is filled with the Porocel–aluminium chloride mixture.

When original charge is spent, top third is removed and a " booster-charge " of aluminium chloride and Porocel added.

From three to six booster charges can be used before it is necessary to clean reactor and put in a new original charge. G. A. C.

1036. Isomerization of *cyclo*hexane. A. P. Lien, E. L. d'Ouville, B. L. Evering, and H. M. Grubb. *Industr. Engng Chem.*, 1952, **44** (2), 351–3.—Apparatus and procedure are briefly described for investigating the effect of aluminium chloride and hydrogen chloride concentrations on the rate of isomerization of commercial *cyclo*hexane. Equilibrium data are given for the conversion of *cyclo*hexane to methyl*cyclo*pentane over the range 0° to 175° C. Reaction rate decreased as a linear function of hydrogen pressure and increased as a function of the square root of the concentration of either catalyst. Results suggest that HCl and $AlCl_3$ equally affect the activity of the catalyst. E. J. C.

Chemical and Physical Refining

1037. Studies of fluidization I.—The critical mass velocity. C. van Heerden, A. P. P. Nobel, and D. W. van Krevelen. *Chem. Engng Sci.*, 1951, **1** (1), 37–49.—Data on the critical mass velocity at which a powdered solid starts to fluidize in an ascending flow

of gas are given. Measurements were made on closely sized samples and mixtures of different sizes of carborundum, iron oxide, and coke, using air, argon, carbon dioxide, nitrogen–hydrogen mixtures, town gas, and methane as fluidizing gas. The proportionality of the critical mass velocity G_0, with the reciprocal value of the kinematic visc μ/ρ of the gas and with the bed density at max porosity ρ_{bm} and the square of the particle dia d was confirmed for $Re < 5$.

Introducing an effective dia d_e and a generalized shape factor B shows that the principal property which determines the resistance to gas flow is the number of particles per unit vol of bed. The equation for determining critical mass velocity is given as

$$R_{e_0} = \frac{0{\cdot}00123}{B} \frac{\rho\rho_{bm}gd^3}{\mu^2}$$

A further equation is suggested for the pressure loss in a fixed bed where the usual porosity term is substituted by a power of the packing ratio. C. J. P.

1038. On the " viscosity " of a bed of fluidized solids. H. Kramers. *Chem. Engng Sci.*, 1951, **1** (1), 35–7.—It is shown that, due to the tendency of the gas to segregate from the dispersion of fine solids, the rheological behaviour of a fluidized bed changes throughout its height. A qualitative discussion on the behaviour of various types of solid is given. It is suggested that heat-transfer coefficients may also be affected in a similar way. C. J. P.

1039. New sweetening poly units at Montreal. H. C. Plummer. *Petrol. Engr*, Jan. 1952, **24** (1), C25.—Three new Linde sweetening units, using copper chloride, oxygen, and 200-mesh clay are now in operation at Montreal East refinery with capacities of 12,000, 6000, and 4000 b.d. for treating light straight-run gasoline, cracked gasoline, and kerosine respectively. E. K. J.

1040. Filtration. A. S. Miller. *Industr. Engng Chem.*, 1952, **44** (1), 63–8.—A review of 172 references. E. J. C.

1041. Continuous filtration—calculation of cake impurity and liquid yield. H. Mondria. *Chem. Engng Sci.*, 1951, **1** (1), 20–35.—Formulæ are given for the separation of solids from liquid by continuous filtration, consisting of the filtration and the washing of the filter-cake by a solvent. The formulæ are derived for a prediluted mixture of solids and liquids, but can be adapted to cases where no predilution is used. Formulæ are tabulated for a continuous-filtration process, and the effects of differing process variables during filtration with a rotary filter are given. A survey of continuous-filtration calculations with recirculation of filtrate is given in tabular form. The beneficial effect of filtrate recirculation on the degree of separation is worked out quantitatively as shown in formulæ, tables, and graphs. The application of these formulæ to the dewaxing of lubricating oils, using butanole–benzene mixtures as diluent and wash solvent, gave good agreement with practical results. C. J. P.

1042. Sulphur reduction in thermally cracked naphtha. W. P. Ballard and A. R. V. Ploeg. *Petrol. Engr*, May 1950, **22** (5), C70.—The reduction of sulphur in naphthas is necessary to increase lead susceptibility and O.N. of finished blended gasoline. This can be effected by : (1) careful selection of the charge stock ; (2) sulphur removal from the charge stock ; and (3) sulphur removal from the product naphtha. (1) is very restricted except in exceptional circumstances, and (2) is usually uneconomical. (3) can be done by removal of mercaptans by caustic soda (or potash), organic solvents, and water, but is only economical if there is a high mercaptan content. If greater desulphurization than mercaptan removal is required, regenerative catalytic vapour-phase desulphurization is preferred because of lower yield loss and less octane depreciation than acid treating and mild hydrogenation, respectively. E. S. L.

1043. Charts simplify determination of percentage of salt removed. O. M. Duncan. *Petrol. Engr*, June 1950, **22** (6), C46.—Knowing the raw crude oil and the desalted crude oil salt contents, the percentage removed is read off. The charts cover salt content of raw crude up to 100 lb NaCl per 1000 brl. E. S. L.

1044. Evaporation. W. L. Badger and R. A. Lindsay. *Industr. Engng Chem.*, 1952, **44** (1), 50–3.—Review of fifty-eight references. E. J. C.

1045. Centrifugation. J. O. Maloney. *Industr. Engng Chem.*, 1952, **44** (1), 39–41.—A review, seventy-nine references. E. J. C.

1046. Crystallization. C. S. Grove, Jr., and J. B. Gray. *Industr. Engng Chem.*, 1952, **44** (1), 41–5.—A review covering eighty-one references. E. J. C.

1047. Catalysts. Anon. *Chem. Engng*, 1951, **58**, 157–68.—A review of methods of selection, development, and manufacture of catalysts in pellet, powder, and granules. Recent applications are to manufacture of detergents, fibres, rubbers, aviation gasoline, etc. D. H.

1048. Patents. U.S.P. 2,571,666 (25.10.47; 16.10.51). D. C. Bond and M. Savoy, assrs to Pure Oil Co. Sweetening hydrocarbon liquids containing mercaptans by contacting with air and alkali solution containing a quinone.

U.S.P. 2,570,278 (29.3.49; 9.10.51). J. W. Ryder, assr to Standard Oil Development Co. Hydrocarbon fraction boiling 400° to 700° F is contacted with aq NaOH, and the partially spent solution used to contact a hydrocarbon fraction boiling 80° to 420° F, the mercaptan content thereby being substantially reduced.

U.S.P. 2,572,519 (16.2.49; 23.10.51). H. A. Ricards and J. W. Ryder, assrs to Standard Oil Development Co. Three-stage sweetening process using in: (*a*) 0·7 to 7% aq NaOH to extract agents increasing solubility of mercaptans in aq NaOH; (*b*) 12 to 15% aq NaOH; (*c*) aq NaOH of conc 1 to 3% less than in (*b*) and containing used aq NaOH from (*a*).

U.S.P. 2,570,277 (24.2.49; 9.10.51). H. A. Ricards and J. W. Ryder, assrs to Standard Oil Development Co. Sweetening process in which hydrocarbon fraction is contacted first with aq NaOH and then with aq NaOH of at least 1 to 3% lower conc containing a solubilizer.

U.S.P. 2,569,984 (27.10.47; 2.10.51). L. C. Fetterly, assr to Shell Development Co. Separating straight-chain hydrocarbons from mixtures with non-straight-chain hydrocarbons in the gasoline and lub.-oil boiling range by forming a crystalline molecular complex with urea.

U.S.P. 2,569,986 (12.3.48; 2.10.51). L. C. Fetterly, assr to Shell Development Co. Fractionating a mixture of straight-chain (A) and branched-chain (B) compounds by treatment with aq urea or thiourea to form urea-A or thiourea-B complexes in presence of a solvent (aliphatic monohydric alcohol, ketone, or ester).

U.S.P. 2,571,380 (23.6.48; 16.10.51). J. E. Penick, assr to Socony Vacuum Oil Co., Inc. Spent adsorbent used for decolorizing is revivified by washing with pet naphtha, mixing the fluidized material with hot regenerated adsorbent, and finally burning off the carbonaceous deposit.

U.S.P. 2,571,107 (7.5.47; 16.10.51). F. W. Breth, assr to L. Sonneborn Sons, Inc. Finely divided carbonaceous carrier particles containing adsorbed H_2SO_4 sludge are blown into a zone maintained at >320° F, where they are flash decomposed, at least part of the carrier being burnt to supply heat and SO_2 being recovered. V. P. P.

Special Processes

1049. Production line treating established. J. C. Albright. *Petrol. Engr*, Oct. 1951, **23** (11), C34–8.—An improved pressure distillate-treating system has been installed at Wilmington, California, refinery, which incorporates a pre-scrubbing operation for the extraction of phenols in a recoverable state. Phenol extraction is carried out until the caustic has a phenol content approaching 30% saturation, when it is found that no mercaptans are dissolved in the solution due to a form of selective absorption. The flow of pressure distillate is continuous from the phenol-extraction system to storage, and so freshly produced pressure distillate is not released to atmosphere, enabling stable finished grades of motor fuel to be prepared. E. K. J.

1050. Choice of grease-making equipment. C. J. Boner. *Petrol. Engr*, May 1950, **22** (5), C7.—Discussion of the main equipment for grease-making functioning for one of the following purposes: (1) movement of fluids, handling either liquid or plastic; (2) heat transfer—to raise the temp to facilitate handling and promote solution or reaction—in some cases cooling is required; (3) mixing to give intimate contact of reactants and to incorporate oil, etc., into the soap matrix; (4) partial or complete dehydration; (5) milling to make the product smoother, or to incorporate solids; (6) vacuum treatment to remove entrained air. Semi-continuous processes are used extensively. Indicating, control, and regulating equipment, as well as materials of construction for pumps, etc., are mentioned. Illustrations of homogenizer and deaerater, Votater for heating, autoclaves, mixers, Stracto semi-continuous oil-circulation heating system, and an Esso semi-continuous plant for manufacture of lubricating grease are given. Five references. E. S. L.

1051. Improvement of Middle East light distillates by catalytic treating over bauxite. C. Padovani, A. Girelli, and C. Siniramed. *Riv. Comb.*, 1951, **5**, 591–608.—The Italian petroleum industry is now processing almost exclusively Middle East crudes. It is well known that such crudes, when distilled, yield straight-run gasolines of extremely low O.N.

An inexpensive method of improving lead susceptibility of light distillates (to meet octane requirements of Italian specifications) is the almost complete removal of sulphur compounds by catalytic treating in vapour phase over bauxite.

Work carried out at the Stazione Sperimentale per i Combustibili on the determination of different types of sulphur compounds in Middle East light distillates is described, and also factors governing the desulphurizing efficiency of different types of bauxite. (Authors' Abstract.)

1052. The Fischer–Tropsch process. C. C. Hall. *Birmingham Univ. Chem. Engr*, 1951, **2**, 84–92.—A review of the process since its early days. S. B.

1053. Fischer–Tropsch synthesis—some important variables of the synthesis on iron catalysts. R. B. Anderson, B. Seligman, J. F. Shultz, R. Kelly, and M. A. Elliott. *Industr. Engng Chem.*, 1952, **44** (2), 391–7.—Effect of pressure, particle size, and alkali content of catalyst on the conversion of a mixture of 50% H_2 and 50% CO were investigated. Catalyst preparation is described in detail. At 237° and 249° C catalyst activity was a linear function of operating pressure for one particular catalyst, whereas it was essentially constant for nitrided and sintered catalysts between 100 and 300 p.s.i.g.

The average catalyst activity increased with decreasing particle size with one exception, while alkali content tended to increase the activity fairly rapidly up to a max, and then reduce it.

Data are tabulated and plotted. Product compositions are given, the gaseous components being estimated by mass spectrometric means and the liquid distillation fractions by infra-red analysis. E. J. C.

1054. Fischer–Tropsch synthesis—effect of nitriding on three types of iron catalyst. J. F. Shultz, B. Seligman, L. Shaw, and R. B. Anderson. *Industr. Engng Chem.*, 1952, **44** (2), 397–401.—(*Cf* Abs. 1053). Nitrided catalysts are stated to be more active than reduced catalysts, and yield a product of low average mol. wt. containing oxygenated compounds. Catalyst pretreatment is detailed. It was found that nitriding two fused catalysts increased their activities up to more than twofold at 300 p.s.i.g., although the increase was lower at 100 p.s.i.g. E. J. C.

1055. Britain's Philblack plant will produce fifty million pounds yearly. E. L. Lomax. *World Petrol.*, Jan. 1952, **23** (1), 36–8.—Carbon-black plant at Avonmouth is described. Furnace process using 70,000 tons/year of U.S. cat cracked dist (gas oil range) produces 20 million lb medium reinforcing "Philblack A" and 30 million lb high reinforcing "Philblack O," about 50% of U.K. requirements. E. B.

1056. Patents. U.S.P. 2,570,925 (4.1.49; 9.10.51). J. F. Eberle, assr to Phillips Petroleum Co. Dehydrofluorination catalyst comprising at least one metal between Mg and Ag in the e.m.f. series admixed with a calcined mixture of a strong inorganic acid with a non-volatile anhydride and the metal salt of this acid.

U.S.P. 2,572,605 (1.4.48; 23.10.51). J. F. Fincke, assr to Monsanto Chemical Co. Sulphonation process in which liq SO_3 containing SO_2 is mixed with liq SO_2 containing a hydrocarbon having <1 group of the type —CH=CH—, the mixed streams being flowed through a nozzle into a zone of lower pressure, complete evaporation of liq SO_2 occurring within the nozzle by the heat of sulphonation, the pressure drop across the nozzle being <40 p.s.i.

U.S.P. 2,571,116 (6.1.50; 16.10.51). M. De Groote and B. Keiser, assrs to Petrolite Corp. Ltd. Water-in-oil type petroleum emulsions are broken by the aid of a hydrophile oxyalkylated phenol—C_{1-8} aldehyde resin demulsifier derived from a mixture of a 2 : 4 : 6-C_4- to C_{14}-hydrocarbon substituted monocyclic monohydric phenol and salicylic acid, the resin mol containing <1 salicylic radical and the alkylene groups containing 2 to 4 carbon atoms and optionally OH substituents in the C_3 and C_4 radicals (U.S.P. 2,571,117–21 relate to the production of this type of resin).

U.S.P. 2,570,611 (20.7.49; 9.10.51). R. W. Towne, assr to Monsanto Chemical Co. Breaking water-in-oil type emulsions by adding trichloracetic acid or its alkali or alkaline-earth salts.

U.S.P. 2,572,633 (10.9.48; 23.10.51). W. C. Lanning, assr to Phillips Petroleum Co. In Fischer–Tropsch process, wax deposits on the catalyst are removed in a finely dispersed state by treating the partially spent catalyst with hydrogen at 600° to 900° F in a regeneration zone, the effluent gas from which is mixed with a normally liquid-product fraction which vaporizes when so mixed and the mixture then cooled to condense the liquid and wax, which are then separately recovered.

U.S.P. 2,569,463 (26.11.47; 2.10.51). Du Bois Eastman, assr to Texas Co. In Fischer–Tropsch process, a fraction boiling in the range 100° to 400° F and containing oxygenated compounds is passed with steam into contact with fuller's earth at 700° to 900° F/1 atm—25 p.s.i.g. to improve octane value.

U.S.P. 2,570,792 (8.12.49; 9.10.51). W. F. Gresham, assr to E.I. du Pont de Nemours & Co. Preparation of polyhydric alcohols by reacting a carbon oxide with hydrogen in presence of Mn and Cr at >1000 atm.

U.S.P. 2,571,151 (14.11.46; 16.10.51). H. G. McGrath, H. J. Passino, and L. C. Rubin, assrs to M.W. Kellogg Co. Liquid-phase oil product obtained in Fischer–Tropsch process is separated into fractions boiling below 200° F, above 430° F, and an intermediate fraction comprising hydrocarbons, acids, and alcohols which is extracted with a light alcohol.

U.S.P. 2,572,734 (16.12.49; 23.10.51). B. R. Kramer, assr to Phillips Petroleum Co. A heavy high-boiling aromatic oil or tar derived from a pet process is separated into: (*a*) a fraction boiling 400° to 700° F; (*b*) a higher-boiling fraction which is hydrogenated to produce a fraction (*c*) boiling 400° to 700° F. (*a*) and (*c*) being passed to a tangential furnace to produce carbon black.

U.S.P. 2,572,595 (18.12.47; 23.10.51). G. N. Cade, assr to Phillips Petroleum Co. Organic fluorine compounds present as impurity in saturated hydrocarbon material is removed by contacting with fluidized Zn, Mg, Cd, Cu, Pb, or Al at 150° to 350° F and absorbing HF formed in carbon. V. P. P.

Metering and Control

1057. Fluid bed flowmeter. C. F. Gerald. *Industr. Engng Chem.*, 1952, **44** (1), 233–5.—A simple tube arrangement is described for measuring the flow of fluidized particles. Calibration curves are illustrated. E. J. C.

1058. Application of automatic control. Pt I. A. M. Platt and G. L. Farrer. *Petrol. Engr*, May 1950, **22** (5), C13.—The following modes of control are considered fully with graphical illustration of the control of the exit temp of an oil stream passing through a steam-heated exchanger: two position (on–off); proportional (throttling); floating and combination modes. Combination modes included are: proportional speed floating, proportional reset, and proportional reset rate mode. Rate, derivative, or pre-act mode is to reduce the deleterious effect of lag and dead time, and is used only in combination with other modes. Two worked examples for proportion-reset-rate mode are given. E. S. L.

1059. Petroleum refinery instrumentation. Pt 2. D. M. Considine. *Petrol. Engr*, Oct. 1950, **22** (11), C24.—Automatic analysers and their use, or possible use, in process control are considered. Raman, mass, visible, infra-red, and ultra-violet spectrometers are mentioned (with the use of the two latter ones for both quantitative and qualitative determinations), together with recording adsorption fractionators (which separate, identify, measure, and collect the components of light-hydrocarbon-gas mixtures and record the data) and low-temp distillation analysers (which are effective in analysing organic compounds, especially hydrocarbons). The development and use of the graphic control panel are discussed. E. S. L.

1060. Petroleum refinery instrumentation. Pt 3. D. M. Considine. *Petrol. Engr*, Nov. 1950, **22** (12), C42.—In designing any control panel reduction in size of the control-room, ease of operation, and added ease in training new operatives are desirable. A graphic panel, the design of which is discussed, is said to have these advantages; standard proven control components should be used. The pictorial flow diagram is drawn up in ten colours, and identification of the variable under control is effected by means of a symbol, *e.g.*, circle will indicate flow, and the colour indicates the point of application. Two types of graphic panels are described, (*a*) a colour-graphic panel on which all controllers are mounted directly below rather than on the pictorial flow diagram, and (*b*) a panel on which all instruments are mounted directly in the flow diagram. For a catalytic cracking plant the estimated cost of panel type (*a*) was 37% above the conventional type, and type (*b*) was 40% above. For a specific job, the length of a conventional panel was estimated at 45 ft, type (*a*) at 22¾ ft, and type (*b*) at 24½ ft. This gives a saving in control-room size and cost, but is not sufficient to outweigh the expense of the panel. E. S. L.

1061. Process control by mass spectrometer. C. F. Robinson. *Chem. Engng*, 1951, **58**, 136–7.—Process lines at Socony Vacuum Oil Co. refinery are sampled and delivered continuously to a mass spectrometer which records the compositions and standardizes itself automatically against a gas of constant composition. A change in conditions can be indicated within 6 min. D. H.

1062. Area type meters in refining applications. J. O. Larson. *Petrol. Engr*, Jan. 1952, **24** (1), C15–20.—A survey is presented of the uses of area-type meters for measuring crude, gas, gasoline products, by-products, acids, sulphur, wax, lubricating oils, caustic, and chlorine in refineries. Operating characteristics are compared for variable-area and variable-head meters in a table under eleven comprehensive headings. E. K. J.

1063. Calibration of differential type liquid level meters. R. Tobi. *Petrol. Engr*, Oct. 1950, **22** (11), C44.—A method of calibration is presented to enable differential measuring instruments (*e.g.*, flow meters) to be used as liquid-level indicators and recorders. It compensates for differences in the specific gravities of seal liquids and the liquids the levels of which are being measured. E. S. L.

Products

Chemistry and Physics

1064. Isomerization mechanism of olefinic hydrocarbons. A. D. Petrov, M. A. Chel'tzova, and M. I. Batuev. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1951, 571–5.—Isomerization of hexene-3 yielded 2-methylpentene and a small amount of 2 : 3-dimethylbutene-1. 4-methylpentene-1 gave 2 : 3-dimethylbutene-1 (50% yield). 2-methylpentene-2 gave 2-methylpentene. Production of mono- and di-alkylalkenes by isomerization of *n*- and *iso*-hexenes and octenes is due to two independent, simultaneously occurring reactions. V. B.

1065. Isomerization of olefinic hydrocarbons on aluminosilicates. A. A. Petrov, A. V. Frost, and M. I. Batuev. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1951, 745–52.—Twelve olefins (C_6 to C_8), both aliphatic and cyclic, were isomerized

by aluminosilicate cat (Houdry type) at 250° C, *i.e.*, in conditions excluding cracking. Liq product yield was 85 to 90%, monomer amounting to 60 to 80%, of which 40 to 60% were saturated compounds. Unsaturateds were separated by anhyd HBr. No evidence of aromatization in monomers was observed. Isomerization mechanism suggested involves reaction between olefin and cat, with formation of intermediate compounds of the alkyl*cyclo*propane type. Rupture of the three-membered ring of the alkyl*cyclo*propanes occurs at the most asymmetric bond; in the unsaturated isomerization products the double bond is preferentially located next to the branched alkyl group. V. B.

1066. Irreversible catalysis of *cyclo*hexene on high-purity activated charcoal. N. D. Zelinskii and G. I. Levi. *Izvest. Akad. Nauk S.S.S.R., Otdel Khim. Nauk*, 1951, 819–20.—Passage of *cyclo*hexene at 450° C over pure charcoal, prepared from sugar and containing only trace impurity (0·01% Fe) and activated by CO_2, yielded benzene (12%) and *cyclo*hexane (24%). Attempts to hydrogenate *cyclo*hexene over same cat gave no result, and cat was likewise inert in attempted reduction of α-nonene with H_2. V. B.

1067. Catalytic air oxidation of higher aromatics to phthalic anhydride. C. R. Kinney and I. Pincus. *Industr. Engng Chem.*, 1951, **43** (12), 2880–4.—An apparatus and experimental procedure for catalytic oxidation of naphthalene, 1- and 2-methylnaphthalenes, 2 : 3-dimethylnaphthalene, coal-tar fractions, anthracene, anthraquinone, phenanthrene, carbozole, and "anthracene salts" to phthalic anhydride are described. Relevant data are given for the tests in which two catalysts were used, one a silica-based vanadium pentoxide catalyst, the other an alumina-based catalyst. E. J. C.

1068. Catalytic hydrocondensation of carbon monoxide with olefins. 6. Hydrocondensation of carbon monoxide with *n*-butylene. Y. T. Eidus, N. I. Ershov, M. I. Batuev, and N. D. Zelinskii. *Ivest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1951, 722–7.—(Cf. Abs. 1451—1951). (**Erratum.** In Abs. 1451—1951, in reference, for "*Tekh.*" read "*Khim.*" and for "424—1950" read "424—1951.") Experiments were carried out on equimolecular mixture of H_2 and C_4H_8 + 2·6 to 6% of CO, under the same conditions as previously. At 2·6% CO 100% of CO and 97·1% of C_4H_8 react, at 6% CO, 100%, and 70·4% respectively. 30 to 35% of the C_4H_8 is reduced to C_4H_{10}. Liquid products ($>C_4$) have b.p. 28° to 276° C and consist of aliphatic hydrocarbons (unsaturateds 28%). After hydrogenation liquid condensate was fractionated; analysis (Raman spectra) showed 24% C_5 (about half of which is *iso*pentane), 15% C_6, 8% C_7, 8% C_8, 9% C_9, as well as higher hydrocarbons. V. B.

1069. Effect of very high pressures on the catalytic properties of aluminium oxide. L. F. Vereshchagin, L. Kh. Freidlin, A. M. Rubinshtein, and I. U. Numanov. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1951, 809–18.—Cat was prepared by pptn from Al nitrate with NH_4OH, washing, and drying at 100° C. Compression was at 20,000 atm in Al container. Reaction studied was dehydration of EtOH at 285° to 320° C; three cat specimens were compared, undehydrated, compressed, and compressed after dehydration at 360° C. Pressed cat was more effective, mechanically stronger, and more stable, *i.e.*, polymerization reactions at its surface occurred less rapidly than with unpressed cat. Dehydrated cat was better than undehydrated. Cat regeneration was by air at 525° C. X-ray examination of cat showed no phase transformation owing to pressure, compressed material being solely composed of γ-alumina, although denser than the uncompressed material, due to lesser porosity. V. B.

1070. Adsorptive and catalytic properties of some bleaching earths. V. T. Buikov and M. I. Kuadzhe. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1951, 487–99.—Fourteen clays from various parts of the U.S.S.R. were investigated with respect to chem and physical characteristics, thermal analysis, electron-microscopic examination, catalytic properties (isomerization of gasoline, cracking of cumene, dehydration of EtOH), sorption and desorption of benzene vapour, bleaching activity towards mineral and vegetable oils. Some of the clays were activated with acid; this was especially desirable for alkaline clays and those with high carbonate content. Some general

relationships between clay structure and bleaching properties were deduced, *e.g.*, presence of amorphous silicic acid, together with minute siliceous skeletal residues of diatoms and radiolaria considerably increases the absorbing power of an earth. V. B.

1071. Sorptive and bleaching properties of natural sorbents. V. T. Buikov. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1951, 678–85.—Ten U.S.S.R. clays (chem analyses given) were investigated by studying sorption and desorption of benzene vapour at 20° C. Pore size was measured, mean effective pore radius was 10 to 85 Å. Bleaching efficacy (F) (ratio of colorimeter readings on oil before and after treatment) is linearly related to effective sorption vol per g (V); for soln of gas oil in kerosine expression is $F = 1 + 7V$. Max bleaching power is shown by earths where ratio of sp. area of adsorption film (S') to sp. area of clay skeleton (S) approaches unity, *i.e.*, bleaching properties, especially for pet products where matter to be removed is mostly large mols, are governed by the intermediate-sized pores. For clays examined range of S' was 12 to 95 and of S 30 to 90 m²/g. V. B.

1072. Solubility of aromatic hydrocarbons in water. R. L. Bohon and W. F. Claussen. *J. Amer. chem. Soc.*, 1951, **73**, 1571–8.—The solubilities in water of the hydrocarbons benzene, toluene, ethylbenzene, *m*-xylene, *p*-xylene, biphenyl, and naphthalene were determined at different temperatures between 0° and 40° C by an ultra-violet method. All the liquid hydrocarbons are shown to have a solubility min near 18° C, which corresponds to a zero heat of solution. The calculated heats and entropies of solution are discussed in terms of ice-like structures and bonding between π electrons of the benzene ring and water. Determination of the solubility of toluene in silver nitrate solution shows the hydrocarbon to be more soluble than in pure water, and complex formation between cation and hydrocarbon is indicated by the heat of solution. W. H. A.

1073. Solubility of ethylene in water. E. J. Bradbury, D. McNulty, R. L. Savage, and E. E. McSweeney. *Industr. Engng Chem.*, 1952, **44** (1), 211–12.—Solubility of C_2H_4 in water is reported over the range 4 to 525 atmospheres for temp of 35°, 45°, and 75° C. E. J. C.

1074. Vapour pressure of benzene above 100° C. P. Bender, O. T. Furukowa, and J. E. Hyndman. *Industr. Engng Chem.*, 1952, **44** (2), 387–90.—Apparatus and method are described for determining vapour pressure of C_6H_6 between 100° and 300° C. Results are plotted and critical constants determined. Comparison is made with previous investigations. E. J. C.

1075. Construction of ternary phase diagram for liquid–liquid equilibria. H. E. Jones and W. E. Grigsby. *Industr. Engng Chem.*, 1952, **44** (2), 378–80.—Apparatus and method are described for determining the plotted equilibrium data for the system benzene–water–trimethylamine at 25° and 70° C. E. J. C.

1076. Phase equilibria in hydrocarbon systems. H. H. Reamer, F. T. Selleck, B. H. Sage, and W. M. Lacey. *Industr. Engng Chem.*, 1952, **44** (1), 198–201.—Volumetric behaviour of the nitrogen–ethane system is reported over the range 0 to 10,000 p.s.i. and between 40° and 460° F. E. J. C.

1077. Vapour–liquid equilibria in methanol binary systems. W. D. Hill and M. van Winkle. *Industr. Engng Chem.*, 1952, **44** (1), 205–8.—Vapour–liquid equilibria are reported for the systems methanol–propanol, methanol–butanol, and methanol–pentanol at 760 mm Hg. E. J. C.

1078. Vapour–liquid equilibria in methanol binary systems. W. D. Hill and M. van Winkle. *Industr. Engng Chem.*, 1952, **44** (1), 208–10.—Data are given on systems methanol–methyl ethyl ketone, methanol–methyl propyl ketone, and methanol–methyl *iso*butyl ketone at 760 mm Hg. E. J. C.

1079. Vapour–liquid equilibria at sub-atmospheric pressures. B. T. Jordan, Jr., and M. van Winkle. *Industr. Engng Chem.*, 1951, **43** (12), 2908–12.—Data are given on the system dodecane–octadecane from 10 to 760 mm Hg pressure.

1080. Vapour-liquid equilibria at sub-atmospheric pressures. K. C. Bachman and E. L. Simons. *Industr. Engng Chem.*, 1952, **44** (1), 202–5.—Vapour–liquid equilibrium data are given for the system acetone–carbon tetrachloride at 300, 450, 600, and 760 mm Hg. E. J. C.

1081. Isobaric heat capacity of methane. E. W. Sledjeski. *Industr. Engng Chem.*, 1951, **43** (12), 2913–15.—Isobaric heat capacities for methane were computed up to 10,000 p.s.i. and 1300° F using the Benedict–Webb–Rubin equation of state. E. J. C.

1082. The reaction of nitrogen atoms with methane and ethane. H. Blades and C. A. Winkler. *Canad. J. Chem.*, 1951, **29**, 1022–7.—Methane reacted with nitrogen atoms at temp above 300° C to produce hydrogen cyanide with an activation energy of 11 k.cal. and a steric factor of 5×10^{-3}. The reaction of nitrogen atoms with ethane was studied at temp up to 295° C; hydrogen cyanide was the only product found in measurable amounts. The ethane–nitrogen reaction was second order, with an activation energy of 7 ± 1 k.cal. and a steric factor between 10^{-1} and 10^{-3}. At high temp, nitrogen-atom consumption was complete in excess ethane, and the hydrogen cyanide production under these conditions, compared with the atom concentration determined by a Wrede gauge, indicated the active species in the nitrogen stream to be only atomic nitrogen. S. B.

1083. Cyclic polyolefins. XII. Isolation of vinyl*cyclo*öctatetraene and *cis*-1-phenyl-1 : 3-butadiene from acetylene polymers. A. C. Cope and S. W. Fenton. *J. Amer. chem. Soc.*, 1951, **73**, 1195–8.—Vinyl*cyclo*-octatetraene and *cis*-1-phenyl-1 : 3-butadiene were found in the mixture of hydrocarbons formed in the preparation of *cyclo*-octatetraene from acetylene. Separation followed extraction with 20% aqueous silver nitrate in which vinyl*cyclo*-octatetraene is soluble and *cis*-1-phenyl-1 : 3-butadiene is insoluble. Vinyl*cyclo*-octatetraene was regenerated from the silver nitrate extracts by treatment with ammonium hydroxide. W. H. A.

1084. Cyclic polyolefins. XIII. Allylic rearrangements in the reactions of *cis*- and *trans*-3 : 5-dibromo*cyclo*pentenes with dimethylamine. A. C. Cope, L. L. Estes, Jr., J. R. Emery, and A. C. Haven, Jr. *J. Amer. chem. Soc.*, 1951, **73**, 1199–204.—Bromination of *cyclo*pentene with two molar equivalents of *N*-bromosuccinimide yielded a mixture of *cis*- and *trans*- 3 : 5-dibromo*cyclo*pentenes (I and II) in 63% yield. Treatment of these *cis*- and *trans*-isomers with dimethylamine resulted in allylic rearrangement with the formation of *trans*-1 : 2-bis-(dimethylamino)-3-*cyclo*pentene (III) in each case. Evidence of the structure of (III) was afforded by catalytic reduction to *trans*-1 : 2-bis-(dimethylamino-)*cyclo*pentane (IV). The samples of (IV) prepared from (I) and (II) *via* (III) were shown to be identical and to be the same as the compound resulting from an independent synthesis. W. H. A.

1085. Cyclic polyolefins. XIV. 3 : 7-dibromo-1 : 2 : 5 : 6-dibenz*cyclo*öctadiene and 1 : 2 : 5 : 6-dibenz*cyclo*öctatetraene. A. C. Cope and S. W. Fenton. *J. Amer. chem. Soc.*, 1951, **73**, 1668–73.—1 : 2 : 5 : 6-dibenz*cyclo*-octadiene prepared from dibromo-*o*-xylene and sodium under conditions of great dilution was brominated with *N*-bromosuccinimide yielding 3 : 7-dibromo-1 : 2 : 5 : 6-dibenz*cyclo*-octadiene in 70 to 90% yield. The structure was confirmed by conversion to the diol which was oxidized to 3-hydroxy-1 : 2 : 5 : 6-dibenz*cyclo*-octadien-7-one hemiketol, whose structure was confirmed by comparison with an identical sample prepared by the Meerwein–Ponndorf reduction of 1 : 2 : 5 : 6-dibenz-1 : 5-*cyclo*-octadiene-3 : 7-dione. Pyrolysis of the diacetate from 3 : 7-dibromo-1 : 2 : 5 : 6-dibenz*cyclo*-octadiene yielded two equivalents of acetic acid with the formation of 1 : 2 : 5 : 6-dibenz*cyclo*-octatetraene. W. H. A.

1086. Cyclic polyolefins. XV. 1-Methylene-2 : 3 : 6 : 7-dibenz*cyclo*heptatriene. A. C. Cope and S. W. Fenton. *J. Amer. chem. Soc.*, 1951, **73**, 1673–8.—Dehydrobromination of 3 : 7-dibromo-1 : 2 : 5 : 6-dibenz-1 : 5-*cyclo*-octadiene by reaction with amines results in molecular re-arrangement and formation of 1-methylene-2 : 3 : 6 : 7-dibenz*cyclo*heptatriene, whose structure was confirmed by oxidation, hydrogenation to 1-methyl-2 : 3 : 6 : 7-dibenz*cyclo*heptadiene, and by independent synthesis. W. H. A.

1087. Dicyclic hydrocarbons. II. 2-Alkylbi*cyclo*hexyls. I. A. Goodman and P. H. Wise. *J. Amer. chem. Soc.*, 1951, **73**, 850–1.—The 2-methyl, 2-ethyl, 2-propyl, 2-*iso*propyl, and 2-butylbi*cyclo*hexyls were prepared by hydrogenation of the corresponding alcohols. The separation and purification of the five isomeric mixtures was effected by passing the products of hydrogenation through silica-gel columns followed by fractionation under reduced pressure. Some physical properties of the resulting five pairs of isomers are recorded. W. H. A

1088. Quantitative inversion of *cis*- and *trans*-alkene isomers : A new synthesis of normal *cis*-alkenes. M. C. Hoff, K. W. Greenlee, and C. E. Boord. *J. Amer. chem. Soc.*, 1951, **73**, 3329–36.—A method is given for the quantitative inversion of configuration about the carbon to carbon double bond in *n*-alkenes. The inversion is carried out in three steps : (i) chlorination to yield a dichloride, (2) dehydrochlorination, and (3) dechlorination by means of sodium in liquid ammonia. The reaction is explained on the assumption that addition of chlorine is *trans* to the double bond, that removal of hydrogen chloride is also *trans*, while dechlorination takes place without change in configuration. Therefore in the first step, symmetrical *cis*- and *trans*-alkenes yield *dl*- and *meso*-dichlorides respectively ; in the second the *d*- or *l*- and *meso*-compound yields *trans*- and *cis*-chloralkenes respectively while in the third step the replacement of chlorine by hydrogen occurs without change in configuration. The method was applied to *trans*-2-octene, *trans*-4-octene, and *cis*-3-hexene, and in each case the isomer of opposite configuration was obtained. W. H. A.

1089. Hydrogen exchange between cracking catalysts and the butanes. S. G. Hindin, G. A. Mills, and A. G. Oblad. *J. Amer. chem. Soc.*, 1951, **73**, 278–81.—In a study of the hydrogen-exchange reactions of a typical silica–alumina cracking catalyst and hydrocarbons, *n*-butane and *iso*butane were brought into contact with a deuterium-enriched catalyst, or the mono-deuterated hydrocarbon was allowed to contact the hydrogen-containing catalyst. After reaction for 1 hr at 150° C, the product was analysed by the mass spectrometer. To explain the observed results in which hydrogen exchange is lower with *n*-butane than with *iso*butane, a three-stage mechanism is proposed in which a hydrocarbon/catalyst complex is first formed which is followed by an exchange of hydrogen between catalyst and complex and the final stage involves a hydride-ion transfer. The reaction mechanism of each stage is discussed.
W. H. A.

1090. Hydrocarbon synthesis catalyst studies. Use of deuterochloric acid. H. I. Weck, S. Meyerson, and H. S. Seelig. *J. Amer. chem. Soc.*, 1951, **73**, 2331–3.—When used iron catalysts from hydrocarbon synthesis are dissolved in hydrochloric acid hydrogen and hydrocarbons are evolved. By using deuterochloric acid instead of hydrochloric acid it is shown that the hydrocarbons are derived from iron carbide and are not adsorbed synthesis products liberated when the catalyst is dissolved. Examination of the deutero-methanes formed indicates that stable iron alkyls do not exist on the used catalyst, and no exchange was observed between hydrogen in a sample of *n*-pentane adsorbed on metallic iron and deuterium in the acid used to dissolve the iron. W. H. A.

1091. Application of the chloromethylation reaction to the syntheses of certain polymethylbenzenes. C. D. Shacklett and H. A. Smith. *J. Amer. chem. Soc.*, 1951, **73**, 766–8.—The polymethylbenzenes *pseudo*cumene, hemimellitene, durene, *iso*durene, prehnitene, and pentamethylbenzene have each been prepared by chloromethylation of suitable hydrocarbons using a modification of the method of von Braun and Nelles.
Reduction to hydrocarbon was found to proceed most satisfactorily when lithium hydride and lithium aluminium hydride in tetrahydrofuran solution was used.
W. H. A.

1092. Eight-membered carbocycles. Identification of the $C_{10}H_{10}$ fraction from *cyclo*octatetraene preparations. L. E. Craig and C. E. Larrabee. *J. Amer. chem. Soc.*, 1951, **73**, 1191–5.—The $C_{10}H_{10}$ fraction obtained by polymerization of acetylene in the presence of nickel cyanide was hydrogenated and the reaction products shown to be *n*-butylbenzene, 1-ethyl*cyclo*-octene and ethyl*cyclo*-octane. The $C_{10}H_{10}$ fraction was separated into two components which were identified as *cis*-1-phenyl-1 : 3-butadiene and vinyl*cyclo*-octatetraene. W. H. A.

1093. Effect of nuclear substitution on the rate of silica–zirconia–alumina—catalysed depropylation of cumene. R. M. Roberts and G. M. Good. *J. Amer. chem. Soc.*, 1951, **73**, 1320–2.—Depropylation of cumene and several nuclear-substituted cumenes in the presence of a silica–zirconia–alumina cracking catalyst at 450° C and space rate 65 moles per litre catalyst per hr was as follows: 1 : 3-dimethyl-4-*iso*propylbenzene, 77%, *p*-cymene, 60%; 1 : 3-dimethyl-5-*iso*propylbenzene, 57%; cumene, 39%; *p*-chlorocumene, 25%; trichlorocumene (mixed isomers), 8%. The methyl and chloro substituents on the aromatic nucleus were not removed under the test conditions, and the same relative order of activity was observed in the depropylation of *p*-cymene, cumene, and *p*-chlorocumene at 400° C. Relative rates predicted for electrophilic displacement of propyl by hydrogen and calculated by an approx molecular orbital method are in agreement with the experimental results except in the case of 1 : 3-dimethyl-5-*iso*propylbenzene, for which theory predicts a depropylation rate the same as that of cumene. It is suggested that dealkylation of alkylbenzenes in the presence of cracking catalysts of the silica–zirconia–alumina type follows the formation of a polar intermediate complex between alkylbenzene and an acidic centre on the catalyst. W. H. A.

1094. Rearrangements involving 1-pentyne, 2-pentyne, and 1 : 2-pentadiene. T. L. Jacobs, R. Akawie, and R. G. Cooper. *J. Amer. chem. Soc.*, 1951, **73**, 1273–6.—1-pentyne or 2-pentyne in alcoholic potassium hydroxide solution at 175° C were re-arranged forming an equilibrium mixture of 1-pentyne, 2-pentyne, and 1 : 2-pentadiene. 1 : 3-pentadiene was not produced in the reaction. Reaction mechanisms are discussed. W. H. A.

1095. Rotational isomerism and thermodynamic functions of 2-methylbutane and 2 : 3-dimethylbutane. Vapour heat capacity and heat of vaporization of 2-methylbutane. D. W. Scott, J. P. McCullough, K. D. Williamson, and G. Waddington. *J. Amer. chem. Soc.*, 1951, **73**, 1707–12.—The vapour heat capacity of 2-methylbutane is reported for five temp between 317° and 487° K, and the experimental values for the heat capacity in the ideal gas state is represented by the equation $C°p = -0{\cdot}01 + 0{\cdot}10608T - 3{\cdot}676 \times 10^{-5}T^2$. The heat of vaporization was determined at three temp, and from the thermal data the following empirical equation for the coefficient B in the equation of state $PV = RT + BP$ was obtained: $B = -577 - 12{\cdot}01e^{1150/T}$ cc/mole. Information about the energy differences between the rotational isomers of 2-methylbutane and 2 : 3-dimethylbutane was obtained from calorimetric entropy and vapour-heat-capacity data. W. H. A.

1096. Exchange reactions of normal paraffins and unsubstituted *cyclo*paraffins with alkyl halides catalysed by aluminium halides. C. P. Brewer and B. S. Greensfelder. *J. Amer. chem. Soc.*, 1951, **73**, 2257–9.—Primary, secondary, and tertiary alkyl halides react with *cyclo*pentane, *cyclo*hexane, propane, and *n*-pentane in the presence of aluminium halide by hydrogen–halogen exchange yielding mainly secondary halides. It has been shown that an olefin and hydrogen chloride can be substituted for a tertiary alkyl halide in the reaction. The reaction mechanism postulated involves the formation of a carbonium ion from the *n*-paraffin or *cyclo*paraffin by removal of a hydride ion from a secondary position in the molecule. W. H. A.

1097. Behaviour of five-membered cyclenes on liquid-phase contact with metal halides. N. I. Shuikin, K. M. Minachev, and N. D. Zelinskii. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1951, 554–9.—1-Methyl*cyclo*pentene-1 treated with $AlCl_3$ (1·2 to 2·4%) at 50° to 75° C for 4 to 12 hr showed no formation of a six-membered ring, but, with increasing severity of conditions, increasing polymerization occurred. Non-production of isomers is due to complex formation between $AlCl_3$ and the cyclene, this is confirmed by inactivity towards *cyclo*pentane of $AlCl_3$ which has reacted with cyclene. 1-methyl*cyclo*pentene-1 was also treated with $SbCl_3$ and $TiCl_4$, both alone and mixed with equi-molar quantity of $AlCl_3$, and also with equi-molar mixture of $SnCl_4$ and $AlCl_3$. No isomer-formation was noted in any case, but polymerization occurred to varying extents. 1-Ethyl*cyclo*pentene-1 was treated with $ZnCl_2$ and $ZnCl_2 + AlCl_3$, again no isomerization was observed and, with $ZnCl_2$ alone, no polymerization occurred. V. B.

1098. Chromyl chloride oxidation of methyl*cyclo*hexane. A. Tillotson and B. Houston, *J. Amer. chem. Soc.*, 1951, **73**, 221–2.—Methyl*cyclo*hexane when treated with chromyl chloride in carbon tetrachloride solution at 35° C showed little tendency to react. The addition of less than 1% of an olefin initiated a moderately rapid reaction, resulting in the formation of a solid addition product in 85% yield. Hydrolysis of the addition compound yielded hexahydrobenzaldehyde in 25% yield. W. H. A.

1099. Deuterium tracers in the pyrolysis of butane and propylene. C. D. Hurd and J. L. Azorlosa. *J. Amer. chem. Soc.*, 1951, **73**, 33–7.—The preparation of butane-1-d and propene-3-d is described.

After pyrolysis of the butane-1-d it was found that the "undecomposed fraction" contained less deuterium than the original material, whereas when propene-3-d was subjected to pyrolysis the "undecomposed fraction" contained the same amount of deuterium as the original olefin. Examination of the results in terms of the free radical mechanism indicates that the parent hydrocarbon which is recovered is not exclusively the original unchanged material but includes hydrocarbon synthesized during the reaction. W. H. A.

1100. An X-ray diffraction study of calcium stearate monohydrate–cetane systems. R. D. Vold and T. D. Smith. *J. Amer. chem. Soc.*, 1951, **73**, 2006–12.—Examination of X-ray-diffraction patterns of calcium stearate–monohydrate–cetane systems which have been quenched and cooled slowly from elevated temp indicates that in sealed tubes the monohydrate begins to lose water at 130° C. The resulting anhydrous soap was not rehydrated on quenching to room temp. A new modification of calcium stearate was observed on slowly cooling ternary systems of soap, cetane, and water from temp above 130° C, and it is suggested that the stabilizing influence of water in such systems is primarily due to its effect on the colloidal structure of the gel rather than to its ability to form calcium stearate monohydrate. W. H. A.

1101. The chemistry of ethylene oxide. II. The kinetics of the reaction of ethylene oxide with amines in aqueous solutions. A. M. Eastham, B. de B. Darwent, and P. E. Beaubien. *Canad. J. Chem.*, 1951, **29**, 575.—The kinetics of the reaction of ethylene oxide in dilute aqueous solution with di- and tri-ethylamines, aniline, and pyridine were investigated, all at 25° C, and over a wide range of hydrogen- and hydroxyl-ion concentrations. The rates were very similar, and can be accurately expressed by the equation

$$-\frac{d\ \text{oxide}}{dt} = R\ (\text{oxide})(\text{amine})$$

Results indicated that basic catalysis does not occur, and if any catalysis by hydrogen or ammonium type ions does occur, it is not in the pH range 4 to 14. A. D.

1102. The chemistry of ethylene oxide. III. Reaction of ethylene oxide in amine solution. A. M. Eastham and B. de B. Darwent. *Canad. J. Chem.*, 1951, **29**, 585.—The rate of the reaction of ethylene oxide in pyridine solution in the presence of strong acids has been found to be dependent on the conc of acid and of oxide over a wide range of cases at 25° C. The specific-rate constant varies markedly with the nature of the acid anion and decreases with increasing basic strength of the anion, while the absence of large salt effects seems to indicate that the anion effect is of a physical rather than chemical nature and the results are attributed to the nature of solutions of electrolytes in solvents of low dielectric constant. A. D.

1103. The influence of cation radius and salt concentration in the salting out of ethyl ether from aqueous nitrate solutions at 25° C. H. G. Heal. *Canad. J. Chem.*, 1951, **29**, 563.—Measurements have been made of the solubility of ethyl ether in aqueous solutions of the nitrates of the alkali metals, the alkaline earths, magnesium and ammonium, tetra-methyl, tetra-ethyl, and tetra-*n*-propyl ammonium. The salting out at infinite dilution of salt, estimated by extrapolation from data from salt concentrations below 0·1 molal, confirms in a general way to the Debye theory with some slight discrepancies. A. D.

1104. Mechanism studies of the Fischer–Tropsch synthesis. The addition of radioactive alcohol. J. T. Kummer, H. H. Podgurski, W. B. Spencer, and P. H. Emmett. *J. Amer. chem. Soc.*, 1951, **73**, 564–9.—In a study of the mechanism of Fischer–Tropsch synthesis, methyl-labelled and methylene-labelled radioactive ethyl alcohol were added to a 1 : 1 carbon monoxide–hydrogen mixture which was passed over a catalyst at about 230° C and under a pressure of 1 atm. Radioactivity measurements of the hydrocarbon products showed that all the methane formed had negligible activity and that the C_5 to C_{10} hydrocarbons had an approx constant activity, while the C_2, C_3, and C_4 hydrocarbons had a slightly lower activity. Degradation of the C_3 hydrocarbons indicated that about 90% of the added carbon atoms are attached to the α-carbon of the alcohol-adsorption complex, while 10% are attached to the β-carbon. It is suggested that ethyl alcohol or some surface complex resulting from adsorption of ethyl alcohol behaves like an intermediate in hydrocarbon synthesis and that the first of the added carbon atoms attach principally to the α-carbon atom of the surface complex. W. H. A.

1105. Studies of the Fischer–Tropsch synthesis. IX. Phase changes of iron catalysts in the synthesis. R. B. Anderson, L. J. E. Hofer, E. M. Cohn, and B. Seligman. *J. Amer. chem. Soc.*, 1951, **73**, 944–6.—Fischer–Tropsch synthesis using a $1H_2$- to -1CO gas showed that during the first few days the α-iron in the reduced fused-iron catalyst was converted to Hägg carbide (Fe_2C). The quantity of iron as Hägg carbide reached a max of 29% in 200 hr, thereafter it slowly decreased through the remainder of the test. Magnetite was formed at the expense of the α-iron, but at a slower rate than the Hagg carbide; the magnetite phase increased during the experiment. These changes in composition are compared with observed changes in catalyst activity, and it is shown that correlation exists between activity and the amount of iron present as Hägg carbide, non-magnetic iron, or the sum of these phases. W. H. A.

1106. Thermodynamic properties of naphthalene. G. M. Barrow and A. L. McClellan. *J. Amer. chem. Soc.*, 1951, **73**, 573–5.—The heat of vaporization of naphthalene was measured and found to be 11,086 ± 30 cal/mole at 209 mm pressure and 440·9° K; from it and published data on the entropy and heat capacity of solid and liquid naphthalene the entropy of naphthalene in the ideal gas state at 440·9° K was calculated. Vapour-heat capacity was determined at 451·0° and 522·7° K and the results used to calculate the heat capacity in the ideal gas state at these temp. Using Pimental and McClellan's vibrational assignment, the thermodynamic functions have been calculated for the temperature range 298·16° to 1500° K. W. H. A.

1107. Thermochemistry for the petrochemical industry. Pt XIX. K. A. Kobe and R. H. Harrison. *Refiner*, 1951, **30** (12), 114–16.—Methods for converting heat capacity and enthalpy data at zero pressure to high pressures are described. A. R. H.

1108. Introduction to chemical reaction calculations. Pt III. A. M. Platt and G. L. Farrer. *Refiner*, 1951, **30** (12), 137–42.—(See Abs. 233.) Examples of calculations are given, and pertinent equations outlined for some of the more complex types of non-catalytic reactions. The factors affecting the rate of catalysed reactions are also discussed. A. R. H.

1109. Flame propagation. II. Determination of fundamental burning velocities of hydrocarbons by a revised tube method. M. Gerstein, O. Levine, and E. L. Wong. *J. Amer. chem. Soc.*, 1951, **73**, 418–22.—A method for determining fundamental rates of flame propagation in tubes is described, and data are given for thirty-seven hydrocarbons, including normal and branched-chain alkanes, alkenes, and alkynes, as well as *cyclo*hexane and benzene. It is shown that irrespective of chain length normal alkanes have a constant flame velocity, except methane, which is somewhat lower. Flame velocity increases with unsaturation in the direction alkanes<alkenes<alkynes, while branching in the mol decreases flame velocity to a slight extent. A comparison is made between the flame-velocities obtained for a number of hydrocarbons and those cited in the literature for the same compounds. W. H. A.

1110. Flame propagation. III. Theoretical consideration of the burning velocities of hydrocarbons. D. M. Simon. *J. Amer. chem. Soc.*, 1951, **73**, 422–5.—The max flame velocities of thirty-five hydrocarbons, including normal and branched alkanes, alkenes, and alkynes, as well as benzene and *cyclo*hexane, are shown to be consistent with the active particle-diffusion theory of flame propagation. The formula derived by Tanford and Pease is modified by inclusion of a term for the total number of mols of water and carbon dioxide formed from a mol of a given hydrocarbon. The rate constants calculated from the modified equation are the same for all the hydrocarbons except ethylene. W. H. A.

1111. Flame propagation. IV. Correlation of maximum fundamental flame velocity with hydrocarbon structure. R. R. Hibbard and B. Pinkel. *J. Amer. chem. Soc.*, 1951, **73**, 1622–5.—An empirically derived relationship between max fundamental flame velocity of hydrocarbons burning in air and hydrocarbon structure is developed. This max velocity is expressed as a function of the concentrations of the various carbon–hydrogen bonds in the hydrocarbon, and is calculated from an equation of the type :

$$\text{flame velocity } (U_f) = N_A K_A + N_B K_B + N_C K_C \ldots$$

where N_A, N_B, N_C, . . . are the concentrations of the various types of carbon–hydrogen bonds and K_A, K_B, K_C . . . are empirically derived flame coefficients. Max fundamental flame velocities calculated for thirty-four hydrocarbons are compared with the experimentally observed values, and, omitting one hydrocarbon, the difference between the observed and calculated values is less than 2%. W. H. A.

1112. Heats of adsorption on carbon black. III. M. H. Polley, W. D. Schaeffer, and W. R. Smith. *J. Amer. chem. Soc.*, 1951, **73**, 2161–5.—The heats of adsorption of *n*-decane and dihydromyrcene (2 : 6-dimethyl-2 : 6-octadiene) have been measured at 100° C on different furnace and channel blacks. The results confirm that the adsorption appears to be of a physical nature and initial values between 2 and 3 k.cal. per CH_2 group in the adsorbate were obtained. Dihydromyrcene is reported to react in some degree with chemisorbed oxygen complex present on the surface of channel blacks, but since this reaction was not observed with other rubber-reinforcing carbon blacks, it is concluded that it is not of primary significance in reinforcing.
W. H. A.

1113. Influence of shear on the dielectric constant of liquids. B. L. Funt and S. G. Mason. *Canad. J. Chem.*, 1951, **29**, 848–56.—Changes in dielectric constant were found when solutions of polar polymers in non-polar solvents were subjected to shear, and the effects of a velocity gradient upon the dielectric constant were studied in solutions of macromolecules, in suspensions, and in liquid crystals. Decreases in dielectric constant under shear were observed for polar polymers in polar and non-polar solvents. For solutions of ethyl cellulose an increase in dielectric constant was obtained. Non-polar polymers showed no changes of dielectric constant under shear. In carbon-black suspensions large changes in dielectric constant at low rates of shear were observed. The experimental results, in general, support the picture of orientation in a shear gradient opposing the orientation in an electric field. For non-polar polymers, where no orientation in an electric field was to be expected, no changes were observed. S. B.

1114. Physical principles of petroleum refining. E. S. Sellers. *Industr. Chem.*, 1951, **27**, 531–5.—Vapour–liquid equilibria necessary for design of dist processes, etc., are based on equilibrium vaporization ratio k, assuming that mixtures of hydrocarbons behave as ideal solutions (generally true except when considerable amounts of methane or ethane present). k varies with temp and pressure. Max temp and pressure at which hydrocarbon mixtures can exist in equilibrium state do not coincide with crit temp and pressure, as is case with a pure component. Shape of curves shows that it is possible to reduce pressure and effect condensation (retrograde condensation) and *vice versa* (retrograde vaporization). Latter may set an upper pressure limit of about 2500 p.s.i. to gas-absorption processes because of possible loss of absorption oil by vaporization. A. C.

Analysis and Testing

1115. A semimicro filtration apparatus. W. F. Cockburn. *Canad. J. Chem.*, 1951, **29**, 715–16.—The apparatus described is a modification of the side-arm test-tube described by Wright and others. The main advantages of this piece of equipment are: (1) permanent all-glass construction avoids contamination of the specimen; (2) the sintered-glass disk may be pre-heated by refluxing solvent; (3) filtration is under pressure, with the result that evaporation, even of volatile solvents, is cut to a min; (4) the apparatus is easily cleaned. S. B.

1116. Analysis of alkylaryl sulphonates. D. Jouslin. *Chim. Anal.*, 1952, **34**, 34–6.—Method enables proportion of sulphonic group attached to nucleus and to side chain to be distinguished. Former is obtained by estimation of phenol formed by NaOH fusion of alkylaryl sulphonate, latter can be estimated by difference from total S content. Temp of NaOH fusion is critical, and should usually be 350° C (±10°), crucible should be removed from oven on termination of fusion (10 min) and not allowed to cool therein. Material is dissolved in H_2O, neutralized to phenolphthalein, and phenol determined by addition of excess Br in CCl_4 and titration of I liberated from added KI. Presence of Na lauryl sulphonate interferes with test, but can be eliminated by Et_2O washing of aq solution of NaOH melt. V. B.

1117. Drage viscometer. A. Lassieur. *Chim. Anal.*, 1952, **34**, 43–4.—Instrument comprises paddle driven by synchronous motor (200 r.p.m.); measurement is made of displacement of mobile stator under influence of drag. Range covered, with various paddles and cups, is 10 to 10,000 cp, with accuracy ±0·2%. Indicating, recording, and controlling types of the viscometer are available, also modifications operating at 64 and 20 r.p.m. for measuring effect of rate of shear on visc. V. B.

1118. Analysis of mixtures of simple aliphatic alcohols by partition chromatography. A. C. Neish. *Canad. J. Chem.*, 1951, **29**, 552.—Employing partition chromatography on celite–water columns, and using carbon tetrachloride and chloroform as developing solvents, mixtures of methanol, ethanol, *iso*propanol, *n*-butanol, and *iso*amyl alcohol have been resolved. A quantitative estimation of each alcohol was performed by dichromate oxidation of the fractions obtained. Size of sample needed for analysis was 0·5 ml of an aqueous solution containing 1 to 5 mg of each alcohol. The method has also been used successfully in the analysis of a mixture of volatile fermentation products containing *n*-butanol, *iso*propanol, ethanol, acetoin, diacetyl, and acetone. A. D.

1119. A new apparatus for rapid carbon determination by wet combustion. J. A. Thorn and P. Shu. *Canad. J. Chem.*, 1951, **29**, 558.—Purpose of this paper is to describe an apparatus with which both volatile and non-volatile samples may be analysed with considerable speed. The apparatus is simple and compact and works on a wet-combustion procedure employing the Von Slyke Solop oxidation liquid. The sample is oxidized and the resultant carbon dioxide absorbed under reduced pressure. From the oxidation flask the carbon dioxide is transferred by diffusion to be absorbed in stirred sodium hydroxide solution, the excess being determined by titration with hydrochloric acid after addition of barium chloride. Samples containing 0·3 mg to 15 mg carbon can be analysed with a probable error of 0·35% in 20 to 25 min. Volatile compounds in aqueous solution may also be analysed, and in all cases sulphur, nitrogen, and halogens do not interfere. Determinations have been made on a wide variety of compounds, including sucrose, cysteine hydrochloride, and cholesterol. A. D.

1120. Road Research Laboratory machine for rapid analysis of bituminous road materials. F. G. Taylor and E. Tattersall. *Rds & Rd Constr.*, May 1951, **29**, 131–2.—The design and development of the Road Research Laboratory machine for the rapid determinaton of composition of a bituminous mixture by the methylene chloride method are described with mechanical details and drawings of the sieving extractor. J. G. H.

1121. Composition of sulphur compounds in petroleum distillates. Pt 3. Identification and analysis of sulphur compounds in the middle distillates. A. Girelli and A. M. Ilardi. *Riv. Comb.*, 1951, **5**, 609–16.—Recent investigations on the subject of sulphur

compounds in the petroleum distillates boiling in kerosine and gas oil range are surveyed. Reactions of complex formation of sulphur compounds with mercuric acetate, chemical reactions with different reagents, hydrodesulphurization followed by the examination of structure of hydrocarbons formed, are briefly reported. (Authors' Summary.)

1122. Fuel oil stability tests. Anon. *Petrol. Engr*, Nov. 1950, **22** (12), C31–2.—A brief discussion on the various tests to study domestic fuel-oil stability is given. There are tests to indicate the condition of the oil at the time of the test and methods of accelerating deterioration before repeating the above tests. Methods employed in the Du Pont petroleum laboratory for investigating the effectiveness of stabilizers are discussed, and a typical procedure that could be conducted by a refiner to prepare a stable fuel oil for sale, is given. E. S. L.

1123. Modern techniques in petroleum testing. III. Gas analysis—other than by light absorption methods. K. R. Garrett. *I.P. Review*, 1951, **5**, 349.—The interest taken in gases derived from petroleum during recent years has naturally caused a corresponding increase in the attention focused upon methods of gas analysis. The tendency, especially in the U.S.A., has been to devise automatic instruments, but these demand skilled operators. This well-documented article indicates more recent developments in detecting impurities and in separating and estimating C_1 to C_6 hydrocarbons. Inflammable gas is determined (as a protection against explosions or fire) in a "combustible-gas detector" by burning the hydrocarbons on the surface of a helical platinum filament and determining the change in resistance due to temp increase. Low-temp distillation, carried out in some kind of distilling bulb fitted with a vacuum-jacketed fractionating column, separates the individual components of gaseous mixtures. Variations in apparatus and details of technique are indicated. The mass-spectrometer method is more speedy and useful for control testing. Adsorption fractionation using activated charcoal has a limited application. Absorption methods are useful, and novel variations are described. Determination of unsaturated hydrocarbons depends upon the use of a specific reagent for each gas to be estimated. The different reagents are enumerated and types of apparatus described. Specific methods of estimating oxygen and moisture are also detailed. R. H.

1124. Modern techniques in petroleum testing. IV. Engine tests of aviation fuels. J. Ogle and C. H. Sprake. *I.P. Review*, 1951, **5**, 377.—Since aero engines have to operate for long periods at constant loads, and even when cruising a relatively high power is needed, freedom from "knock" is of vital importance. Before the war, tests to determine the anti-knock value of aviation spirits were confined to the CFR Motor Method or the U.S. Army Aviation Method—essentially "weak mixture" ratings corresponding to cruising conditions. The intensive developments in fuels which took place from about 1938 onwards soon showed the importance of "rich-mixture" ratings to differentiate between fuels with the same "weak-mixture" rating. The development of the full-scale rich-mixture test unit is described and the reasons for its unsuitability detailed, together with the subsequent development of the laboratory test unit for the routine determination of "rich-mixture" ratings. Co-operative work along such lines resulted in 1941 in the introduction in America of the AFD-3C Supercharge Method. This was adopted in the U.K. with a certain number of modifications. The U.S. Army-Navy (A.N.) performance scale was introduced into the U.S.A. to indicate relative engine performance rather than merely the composition of the matching fuel blend. Development of weak-mixture rating test methods and a description of reference-fuel scales are also included. R. H.

1125. A new engine-testing and development laboratory. Anon. *Scientific Lubrication*, June 1951, **3** (6), 25–8.—The development of lubricant testing is remarked, and emphasis is laid on the necessity for engine testing under controlled conditions. The new engine-testing and development laboratories of Snowden, Sons and Co. Ltd. are illustrated and described in some detail. J. G. H.

1126. Modern techniques in petroleum testing. V. Road testing the anti-knock quality of motor gasolines. H. J. Eatwell. *I.P. Review*, 1951, **5**, 421.—Knock or detonation in a spark-ignition engine limits the engine efficiency and is affected by engine design,

operating conditions, and fuel composition. A number of laboratory testing methods are used for determining this property, but such a determination merely indicates the performance of average fuels in average engines. Hence to get specific information it is necessary to develop road techniques capable of assessing this property. Also it is necessary to be able to relate results obtained in the laboratory with actual practical performance. All such road-test methods are based upon comparison with reference fuels under full throttle. Six methods are described. The Uniontown or Knock Intensity Test procedure needs no special instrumentation and depends upon audible comparison. The Borderline Test procedure needs special instrumentation but gives information over the whole range of engine speeds. A modification of each of these methods is also described. The Percent Knock-Free Vehicles and De-celerating Borderline Tests are also used. The first of these requires the use of a large number of vehicles, while the second is similar to the Standard Borderline Test Method. The method of preparing vehicles for test is described, and sections upon Reference Fuels and the relationship of road testing with laboratory testing included. R. H.

1127. Patent. U.S.P. 2,571,470 (17.4.48; 16.10.51). W. B. Milligan, assr to Shell Development Co. Apparatus for determining the volatile constituent of a liquid mixture, *e.g.*, water content of crude oil, in which the liquid is flowed at constant temp and flow rate through an orifice, the pressure difference between opposite sides being continuously indicated, *e.g.*, on a gauge. V. P. P.

Crude Oil

1128. Sidi Fili (Morocco) crude. Anon. *Rev. Inst. franç. Pétrole*, 1952, **7**, 3–11.—A report from the applied research section of the I.F.P. Highly paraffinic crude has d_4^{15} 0·840, flash (closed) 30° C, wax 8%, S 0·05%, hexane-insol 3·3%, visc. 30° C 8·4 cs, pour 21° C, 42% at 275° C. Pilot-plant atm/vac dist separated crude into 1% fractions (analyses given) and 17·3 vol-% residue. Gasoline (211° C E.P., yield 22%, has O.N. (motor) 15; gas oil (237° to 350° C, yield 28·8%) has cetane No. 75, nil S, pour −7° C. Vac bottoms: d_{20} 0·991, wax 16%, S 0·33%, pen (50° C) 80, hexane insol 18·7%, m.p. (R & B) 49·8° C. V. B.

1129. Analysis of Italian crude oils. G. C. Facca, G. Roberti, and E. Sommariva. *Riv. Comb.*, 1951, **5**, 504–36.—Samples of Italian crudes, drawn from producing wells or seepages distributed throughout the whole of Italy and Sicily, have been analysed.

Their principal characteristics and the U.O.P. characterization factors are given, while for most of them a complete analysis has been carried out according to the U.S. Bureau of Mines method, leading to calculation of the correlation index and the establishment of the base of the oil. Some ring analyses have also been made.

Finally, the correlation between the crude oils and the horizons from which they originate has been discussed.

Twenty-six tables. (Authors' Summary.)

Gas

1130. Gas revolution. H. D. Ralph. *Oil Gas J.*, 20.12.51, **50** (33), 175.—Underground storage reservoirs now or shortly to be in operation in the U.S. will store nearly one-sixth of the annual gas production of that country. Their use allows gas produced with oil to be stored during summer months against the winter demand, thus saving waste. At present 11% of U.S. gas production is flared for want of a steady market.

Most underground storage now consists of depleted gas fields. Old oil reservoirs may be used, but residual oil produced with the stored gas raises problems most gas companies prefer to avoid. Some storage is being developed in water sands which have never held oil or gas. A high reservoir permeability is desirable to reduce compression costs and give good delivery rates. Cleaning of the gas prior to injection is important to avoid plugging of the formation around injection wells. J. C. M. T.

1131. Analyses of Italian natural gas. E. Pera. *Riv. Comb.*, 1951, **5**, 537–55.—The results have been grouped into tables of the analysis of Italian natural gases, derived

either spontaneously or by borings. Work has been carried out under the auspices of the AGIP during the past twenty-five years.

These analyses give the composition of the gas, and also establish whether the gas has some connexion with the oilfields. The determination of the higher hydrocarbons has been carried out by means of the Jaenger method, by which is determined the increase in volume of gas after combustion on copper oxide, the percentage of higher hydrocarbons being expressed as ethane. (Author's Summary.)

Engine Fuels

1132. Oxidation, decomposition, ignition, and detonation of fuel vapours and gases. Pt XVIII. The operation of a carburettor type engine by compression ignition with diethyl ether or acetaldehyde as the fuel. R. O. King, E. J. Durand, and A. B. Allan. *Canad. J. Tech.*, 1951, **29**, 382–90.—Diethyl ether and acetaldehyde knock violently when used as fuels for carburettor engines in normal temp and mixture strength conditions. The experiments described in this paper, using a CFR knock-testing engine and taking special precautions, show that in relatively low-temp conditions both substances can be used at any ignitible mixture strength at C.R.s varied accordingly and that, in the circumstances, ignition can be either by spark or compression. The nuclei required for ignition by compression are believed to be the fog particles which are known to be formed in heated mixtures of air with diethyl ether or acetaldehyde prior to explosive ignition. The running on compression ignition was without irregularity for both diethyl ether and acetaldehyde. S. B.

1133. Gasoline combustion—effect of boron or silicon compounds. E. C. Hughes, S. M. Darling, J. D. Bartleson, and A. R. Keingel, Jr. *Industr. Engng Chem.*, 1951, **43** (12), 2841–3.—Full-scale engine studies showed that small amounts of borates, borines, ethyl sulphate, and silicone were largely successful in repressing the increased octane requirements of engines after continued operation on leaded fuels. This increased octane requirement is due to a deposition of carbonaceous and inorganic lead compounds on the surfaces of the combustion chamber. Boron compounds and silicone compounds were ineffective for engines where the deposit already existed. Data are tabulated and plotted. E. J. C.

1134. Precombustion reactions in an engine. C. Walcutt and E. B. Pifkin. *Industr. Engng Chem.*, 1951, **43** (12), 2844–9.—The apparatus and experimental procedure for investigating precombustion reactions of sixteen different synthetic fuels, some of them leaded, is described. The results were thermodynamically analysed, and it was concluded that resistance to knock cannot be directly related to heat liberated during precombustion reactions. E. J. C.

1135. Lean flammability limit and minimum spark ignition energy. J. B. Fenn. *Industr. Engng Chem.*, 1951, **43** (12), 2865–9.—A theoretical analysis is applied to experimental data obtained for the ignition energy and lean-limit data for various fuels. It is suggested that the association of lean-limit flame temp with activation energies should prove useful in solving other combustion problems. Tabulated data are given for sixty-three hydrocarbons. E. J. C.

1136. Spontaneous ignition temperatures. J. L. Jackson. *Industr. Engng Chem.*, 1951, **43** (12), 2869–70.—Spontaneous ignition temp and ignition delay are given for ninety-four pure hydrocarbons and fifteen commercial fluids as determined in a crucible type of apparatus. E. J. C.

1137. A calcium–nickel phosphate dehydrogenation catalyst. E. C. Britton, A. J. Dietzler, and C. R. Noddings. *Industr. Engng Chem.*, 1951, **43** (12), 2871–4.—A chromium oxide promoted calcium–nickel phosphate catalyst has been developed for dehydrogenating *n*-butanes to 1 : 3-butadiene, using superheated steam. Ultimate yields of 93 to 97% of 1 : 3-butadiene have been obtained in laboratory equipment at conversion levels of 20 to 45%, and yields of 86 to 88% at conversions of 35% *n*-butenes in plant operations. A number of variables are discussed. E. J. C.

1138. Adiabatic flame temperature in jet motors. W. S. McEwan and S. Skolnik. *Industr. Engng Chem*, 1951, **43** (12), 2818–22.—Adiabatic flame temp is of interest in obtaining the specific impulse of a propellant. A knowledge of the average mol. wt. and ratio of specific heats of the combustion products is also required to determine the specific impulse. Computation of the products of combustion is described, and such calculations as were carried out on flame temp of low propellants were essentially independent of pressure. Flame temp of high propellants were pressure dependent. E. J. C.

1139. Dual-fuel combustion in diesel engines. M. A. Elliott and R. F. Davis. *Industr. Engng Chem.*, 1951, **43** (12), 2854–64.—Current interest in the commercial application of dual-fuel combustion in diesel engines has prompted an interpretation of data on this type of combustion obtained incidental to studies of the hazards of operating diesel engines in flammable gas–air mixtures.

The lower limit of flammability of the combustible gas in the compressed gas–air mixture is an important consideration in dual-fuel combustion. If the concentration of gas is greater than the lower limit, flame propagation throughout the gas–air mixture and the attendant rapid rate of heat release results in engine-operating difficulties and "knock." If the concentration of gas is below the lower limit of flammability, the gas does not react completely with oxygen unless it is in or immediately adjacent to an inflamed or high-temp region. The fraction of gas reacting increases with an increase in either liquid fuel–air ratio or concentration of gas, and is affected by type of engine and engine speed.

The results of tests made with natural gas, propane, butane, and hydrogen can be applied to the design and operation of dual-fuel combustion systems. (Author's Abstract.) Data are plotted and tabulated. E. J. C.

1140. Diesel engine exhaust products. E. W. Landen. *Industr. Engng Chem.*, 1951, **43** (12), 2849–54.—An examination of the suitability of the condensation method for evaluating diesel-engine exhaust products. Results from nine fuels in one diesel engine showed that some organic liquids were exhausted at all engine loads. In general, organic liquids, both water-soluble and insoluble, showed a slight max at the intermediate loads, but organic acids decreased with increasing load.

Of the three combustion systems tried, direct injection produced more solid carbon, and the Lanova system more liquids than the precombustion-chamber engine. Comparison of organic acids to total acids exhausted showed that double-chamber engines were similar.

The method can be used to measure fuel differences, to evaluate engine-deposit-forming tendencies and exhausted products. E. J. C.

1141. Carbon formation in gas turbine combustion chambers. E. S. Starkman, A. G. Cattanev, and S. H. McAllister. *Industr. Engng Chem.*, 1951, **43** (12), 2822–6.—Carbon formation in gas turbines is objectionable because of reduced efficiency, possibility of hot spots with subsequent tube buckling, and erosion or blockages caused if loose carbon broke away from the tube. An apparatus and procedure are reported for testing carbon deposition by different paraffinic, naphthenic, and aromatic fuels, and it was found that tendency to deposit carbon increased in that order. For a fixed C to H ratio, deposits decrease as volatility increases, more generally increasing with specific gravity. Increased air temp, air-to-fuel ratio and decreased pressure minimize the deposits.

A formula was derived by which the tendency of a fuel to deposit carbon could be predicted from its characteristics. E. J. C.

1142. Atmospheric pressure apparatus for studying ignition delay. A. Boodberg and I. Cornet. *Industr. Engng Chem.*, 1951, **43** (12), 2814–18.—A simple laboratory apparatus is described for determining the self-ignition temp and ignition delay of diesel fuels, with or without the presence of additives. *Iso*amyl nitrate was used as the ignition accelerator.

Data obtained indicated that two or more competing mechanisms were present in the systems investigated. E. J. C.

1143. Heavy fuel oil for auxiliary engines. J. Smith. *Motor Ship*, Jan. 1952, **32** (382), 388.—An account of work carried out by The National Gas and Oil Engine Co.

to determine (*a*) whether fuels of visc up to 3000 sec would burn efficiently in a type of engine used as a marine auxiliary, and (*b*) the cylinder-wear rate of such an engine when using a heavy fuel. Results are given of 1000 hr running with a single-cyl, four-stroke engine of 9 inches dia and 12 inches stroke, with direct injection with a four-valve cyl head. From the tests it would appear that by controlling engine conditions the wear rates can be reduced to those expected for an engine running on gas oil. There appears to be no need to use a detergent lubricating oil, all the tests having been carried out using an SAE 30-grade straight mineral oil. Conclusions as to the satisfactory operation of engines on boiler oil are not possible yet, because the tests are incomplete and work is still proceeding. The article is fully illustrated by diagrams and tables. U. M.

1144. Desalting of marine diesel engine fuels. C. Muller. *Rev. Inst. franç. Pétrole*, 1952, **7**, 12–14.—Complete desalting of fuel oil is achieved by washing with hot fresh water containing 0·1% demulsifier, followed by centrifuging (20 min at 5000 r.p.m.). 100 ml water was used for 117 g oil, water can be re-used four to five times, thus indicating possibility of full-scale utilization of method at sea. Best demulsifiers were Na oleate and Na alkyl sulphate (21% concentrate); former gives somewhat better results, except with hard water, when latter is preferred. Analytical procedure for Cl determination is based on that of Dickey and Sorg (*Refiner*, 1948, **27**, 598); for NaCl content > 200 mg/kg error is $< 5\%$, for < 100 mg/kg it can reach 10%. IP method 77/49 is considered too slow and inaccurate. V. B.

1145. Tetra-ethyl lead in various pure hydrocarbons. W. I. Zang and W. G. Lovell. *Industr. Engng Chem.*, 1951, **43** (12), 2826–33.—The effectiveness of T.E.L. as a knock suppressor was determined for paraffins, naphthenes, aromatics, and olefins. Generally, T.E.L. was more effective in the paraffins and naphthenes, where the gain for a given addition of T.E.L. was substantially a constant percentage, irrespective of initial octane rating before leading or change in engine-operating conditions.

In olefins and aromatics T.E.L. addition gave varied results. This was attributed to molecular structure or position of the double bond. E. J. C.

1146. Knock resistance of pure hydrocarbons. H. K. Livingston. *Industr. Engng Chem.*, 1951, **43** (12), 2832–40.—A correlation of O.N. with chemical structure of hydrocarbons is presented. Predicted knock ratings for 108 different hydrocarbons were consistent with experimental results. Knocking resistance is a function of electronic effects contributed by the following retarding groups: methyl, *tert*-alkyl, vinyl, methylene (in ring compounds), and phenyl. Eight rules are formulated for calculating "structural retardation factors" of hydrocarbons. E. J. C.

1147. Anti-knock agents and additives for fuels. G. Roberti and E. Pipparelli. *Riv. Comb.*, 1951, **5**, 556–67.—The use of T.E.L. as an anti-knock agent in gasoline has been widely developed, and other additives have been proposed either as anti-knock agents or for other purposes.

Metallic and non-metallic compounds are examined from the point of view of their properties; differences indicating a different anti-knock mechanism have been pointed out. (Authors' Summary.)

1148. Patents. U.S.P. 2,570,402 (22.12.47; 9.10.51). D. R. Stevens and A. C. Dubbs, assrs to Gulf Research & Development Co. Bis (2-hydroxy-3-butyl-5 methyl-phenyl) methane (where butyl is *sec*- or *tert*-butyl)—as anti-oxidant for oil.

U.S.P. 2,571,092 (21.8.48; 16.10.51). D. Wasserman and S. Caplan, assrs to Harvel Corp. A cracked gasoline containing 4-aminocardanol as anti-oxidant. V. P. P.

Gas Oil and Fuel Oil

1149. Reduction of the vanadium content of residual petroleum fuels by solvent precipitation. W. Sacks. *Canad. J. Tech.*, 1951, **29**, 492–5.—A series of five vanadium-containing residual fuels with a vanadium content varying from 8·4 to 126 p.p.m. by wt, and also containing iron (7·5 to 36 p.p.m.) and nickel (1·5 to 19 p.p.m.) were treated with *n*-pentane and the reduction in vanadium, nickel, and iron content by asphaltene

precipitation studied. Vanadium is precipitated with the *n*-pentane asphaltenes (83 to 95% with 6 : 1 ratio of solvent to fuel) together with the major portion of iron and nickel compounds. Comparative precipitations on a Venezuelan fuel with petroleum ether (b.p. 30° to 60° C), naphtha (b.p. 75° to 120° C), acetone, diethyl ether, *n*-pentane, and ethyl acetate showed that the amount of vanadium removed is approx proportional to the asphaltene yield, but the naphtha fraction did not remove any appreciable amount of vanadium. S. B.

Lubricants

1150. Pennsylvania gear lube and automatic transmission oils. T. J. Garin. *Producers' Monthly*, Feb. 1951, **15** (4), 29–33.—The requirements of lube oils for use in automotive transmissions and couplings are discussed. R. B. S.

1151. Lubricating greases from Pennsylvania oils. T. J. Garin. *Producers' Monthly*, Apr. 1951, **15** (6), 34–5.—The manufacture of lubricating greases for a variety of applications is discussed. R. B. S.

1152. Mechanical breakdown of soap-base greases. R. J. Moore and A. M. Cravath. *Industr. Engng Chem.*, 1951, **43** (12), 2892–7.—Electron micrographs of sodium-, calcium-, lithium-, and barium-base greases showed that breakage of the soap fibres occurred during work softening. Penetration values decreased logarithmically with time of working in most cases. A theoretical explanation is put forward to account for the phenomena. E. J. C.

1153. Draft [German] specifications for "standard lubricating oils", "lubricating oils D", and "dark oils and axle oils". R. Urlass. *Erdöl u. Kohle*, 1952, **5**, 33–8.—"Standard lubricating oils" (DIN 51501) are intended for general lubricating purposes at temp $> 50°$ C where special requirements, *e.g.*, oxidn resistance, low temp flow, are not called for. Nine visc grades (9 cs at 20° C to 122 cs at 50° C) are stipulated, the designations are in Engler units (2.1E20 to 15E50). Min flash range is 100° to 200° C, pours vary from $< -10°$ to $< 0°$ C; all grades have acid val 0·3 max, ash 0·02% max, hard asphalt nil. Recommendations as to appropriate grade for varying lubricating service (bearing type, load, temp) are included. "Lubricating oils D" (DIN 51504) covers a lower-quality series (seven oils, 9 cs at 20° C to 99 cs at 50° C) for use at temp $> 40°$ C. General requirements are acid val 1·5 max, ash 0·3% max, hard asphalt 0·3% max. Flash and pour limits as for previous series. "Dark lubricating oils and axle oils" (DIN 51505) specifies two grades (summer and winter) differing only in pour ($< +5°$ C and $< -10°$ C respectively), other requirements are visc (50° C) 30 cs min, flash 140° C min, acid val 3·0 max, ash 0·3% max, hard asphalt 2·0% max. V. B.

1154. High pressure characteristics of lubricating oil. W. C. McCrone. *Producers' Monthly*, June 1951, **15** (8), 37–9.—An apparatus is described for studying the compressibility and visc of lubricating oils at extremely high pressures of the order of several hundred thousand p.s.i.

Experimental data on the compressibility and visc of typical lube oils are presented. At a characteristic high pressure each of the oils studied appears to solidify, and the pressure at which this occurred was termed the solidification pressure. Paraffinic oils show greater compressibilities and lower visc under high pressure than naphthenic oils, and the solidification pressure is higher for paraffinic oils than for naphthenic oils. R. B. S.

1155. The graphoid surface—an aid to oiliness. Anon. *Scientific Lubrication*, July 1951, **3** (7), 25–6.—The current supply position with respect to fatty acids presents added opportunities for the utilization of colloidal graphite as a lubricant. The special properties of colloidal graphite as forming a slippery surface in a bearing face and facilitating the greater absorption of oil through this surface are discussed together with the concentrations necessary for specific purposes. J. G. H.

1156. Colloidal structure of technical oil dispersions. E. H. Kadmer. *Erdöl u. Kohle*, 1951, **4**, 771–7.—Description of dispersions, principally oil in water, is given, and the effects of interfacial tension and visc on emulsifying power are discussed. Illustrated examples are shown of the micro-structure of various boring, cutting, and industrial oil emulsions and the importance of soap and sulphonate constituents noted. American investigations of lubricating greases containing soaps of various bases, by means of the electron microscope, are described with the aid of photographs of colloidal structures of such dispersions. Advisability of thorough microscopic inspection of motor oils after use and of greases is stressed. Photomicrographs are given of straight and doped lubricants showing changes due to ageing and wear; possible improvements by centrifuging are described. P. V.

1157. Use of molybdenum disulphide in association with phosphated surfaces. F. T. Barwell and A. A. Milne. *Scientific Lubrication*, Sept. 1951, **3** (9), 10–14.—The anti-seizure properties of phosphate coatings on ferrous materials are noted, and the importance of adequate lubrication is stressed. Details are given of a series of wear tests on plain mild steel and on phosphated steel treated with molybdenum disulphide and paraffin wax as lubricants. The apparatus and procedure employed are discussed and results given in graphic form. These indicate that the bonding of molybdenum disulphide to a phosphated steel results in a bearing surface with excellent wear characteristics. The bonding as opposed to rubbing of molybdenum disulphide on the steel surface is an essential for satisfactory performance. J. G. H.

1158. Selection of oils for industrial hydraulic systems. A. C. Smith. *Scientific Lubrication*, July 1951, **3** (7), 20–4, 26.—The development of hydraulic systems is briefly described, and the hydrokinetic and hydrostatic systems are distinguished. The special properties of mineral oil as a hydraulic medium are noted, and variations in compressibility with composition and visc are considered, together with difficulties occasioned by the solution and entrainment of air. Oxidation stability, ability to prevent corrosion effects on flexible materials, and demulsibility are discussed. The relations between visc and pressure, V.I., and pour points are indicated, together with general viscosity requirements for hydraulic systems and for individual components. J. G. H.

1159. Hydraulic fluids simplified. G. R. Schmitt. *Lubr. Engng*, Aug. 1951, **7** (4), 168–73.—The functions of a hydraulic fluid are enumerated, and the main causes of failure in hydraulic systems indicated, together with conditions of the fluid conducive to breakdown. The significance of visc, lubricity, and stability are considered, the last with special reference to the use of additives. The maintenance of the individual components of a hydraulic system is discussed, together with service periods, flushing and cleaning and the reconditioning of oils. Typical pump manufacturers' recommendations for hydraulic oils are also presented. J. G. H.

1160. Mechanism of grinding and the function of the lubricant. J. O. Outwater. *Lubr. Engng*, June 1951, **7** (3), 123–4, 144.—The special features of the grinding process are indicated, and details are presented of an investigation into the mechanism of grinding. This comprises the displacing of the metal at near its melting point in the form of a furrow, which oxidizes and cools in an erect position, after which it is struck by following grains of the grindstone and broken off by a scouring action against the surface. The broken-off piece is ejected by the wheel, and the friction so generated will be reduced by a good boundary lubricant. J. G. H.

1161. Cause and reduction of metallic wear. F. T. Barwell. *Mech. World*, 21.12.51, **130**, 575.—Summary of paper read to Inst. of Engrs and Shipbuilders in Scotland. Wear may be defined as the unintentional removal of material from a surface. Various types of wear are discussed. Scuffing occurs under conditions of high load and high speeds due to localized breakdown of the protective film, resulting in melting and welding. Phosphating of surfaces, and the use of E.P. additives to form protective films at points of weakness reduce tendency to scuffing, but the author states that E.P. additives may increase the rates of wear. Fretting corrosion may be due to particles of metal being broken away and forming abrasive oxides which intensify wear. Phosphating of surfaces and the presence of oil minimize the rate of attack. T. T.

1162. Investigation of the flow and effect of cutting oil in machinery operations. W. E. Lauterbach and E. A. Ratzal. *Lubr. Engng*, Feb. 1951, **7** (1), 15–19.—Results are presented of an investigation into the flow and effect of cutting oil in planing and turning operations conducted at surface speeds between 2½ and 200 f.p.m. It was found that for cutting speeds below 10 f.p.m. the cutting oil penetrated between the tool and the work-piece and between the tool and chip, entering from the clearance crevice and not from the rake crevice. At higher cutting speeds, penetration of the cutting oil between the tool and work-piece and between tool and chip from either crevice could not be detected. J. G. H.

1163. Textile spindles and their lubricants. F. S. Jones. *Lubr. Engng*, June 1951, **7** (3), 114–16.—The significance of spinning spindles in the textile power scheme is explained, and types of spindle in common use are described and illustrated with notes on their inspection and use. The selection of the most suitable oil for special types of spindle is discussed, and the importance of systematic lubrication schedules emphasized. J. G. H.

1164. Wire rope lubrication. Anon. *Scientific Lubrication*, June 1951, **3** (6), 11–15, 33; (7), 10–12.—The wide field of application of wire rope is remarked, and the earlier work of Biggart and the Safety in Mines Research Board, as well as more recent investigations of the lubrication of wire rope, are discussed in some detail and the advantages of zinc-coated ropes enumerated.

In the second article the functions of rope lubricants are enumerated, and the necessity for internal lubrication during manufacture is emphasized, the methods employed being briefly described. The properties of rope lubricants, special formulations for tropical temp, and the incorporation of graphite in rope dressings are considered. Factors leading to rope failure are indicated. J. G. H.

1165. More lubrication problems overseas. R. W. Tong. *Scientific Lubrication*, July 1951, **3** (7), 13, 14, 26.—The casual manner in which maintenance is carried out is remarked, and lubricator sight glasses, crankcase oil dilution, and the necessity for distinct instructions and instruction books are discussed. J. G. H.

1166. More lubrication problems overseas. R. W. Tong. *Scientific Lubrication*, Sept. 1951, **3** (9), 24–6.—The desirability is stressed of the most simple types of lubrication equipment for machinery intended for use overseas. Points discussed include drip feeds, the positioning of mechanical lubricators, pressure gauges, dipsticks, oil pumps, filters, distribution lines, and pump valve gear. J. G. H.

1167. Lubrication, its importance to plant fire safety. R. G. Shepard. *Lubr. Engng*, Apr. 1951, **7** (2), 68.—An analysis of some 20,000 industrial fires rated friction as the second most important cause, 14% of total, being exceeded only by electrical failures, of which it is suggested a considerable proportion were due to overloading attributable to excessive machine friction. The development of lubricant consciousness in the textile industry and its relationship to the reduction in loss through fire is indicated. J. G. H.

1168. The use of detergent lubricants. F. T. Brown. *Motor Ship*, Jan. 1952, **32** (382), 414.—Use of detergent oils with diesel engines running on boiler oil is suggested. Although conventional pure mineral cyl lubricant has appeared adequately to fulfil its desired function when used with boiler oils of fairly consistent quality, in one case where detergent oil had been used, in four of the eight main engine cyl in each of two ships, there were fewer seized or fractured rings in the main and exhaust pistons, deposits in the exhaust and scavenge ports were of a more pliable nature, and close inspection revealed an improved and more effectively oil-wetted surface finish, all achieved with a slightly reduced oil feed. It is possible that beneficient effects may result from detergent oils when burning high-sulphur fuels. A brief history is given of the development and use of detergent oils. U. M.

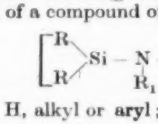
1169. Patents. U.S.P. 2,570,846 (20.3.47; 9.10.51). F. P. Otto, O. M. Reiff, and R. W. Barnett, assrs to Socony-Vacuum Oil Co. Mineral lub oil composition containing an ester of a C_{14} alcohol with a reaction product of maleic anhydride and styrene as pour-point depressor.

U.S.P. 2,572,557–8 (29.1.48; 23.10.51). J. M. Butler, assr to Monsanto Chemical Co. Mineral oil composition of improved visc characteristics containing: (*a*) polystyrene substituted in the aromatic nuclei with an ester R′OOCR, wherein R′ = C_{1-20} alkyl, R = C_{9-10} mono-olefine; (*b*) alkylated polystyrene, mol. wt. >20,000, containing >1·5 *iso*propyl substituents per styrene unit.

U.S.P. 2,572,000 (31.12.48; 23.10.51). J. D. Bartleson, assr to Standard Oil Co. Anti-oxidant and anti-sludge additive for mineral lub oil comprising a mineral oil and a reaction product of NH_3 with P_4X_3, where X is a member of the sulphur family.

U.S.P. 2,571,332 (30.12.47; 16.10.51). J. W. Brooks, assr to Socony-Vacuum Oil Co. Mineral lub oil containing as an anti-oxidant a thiophenethiol–phosphorus halide reaction product, production of which is claimed in U.S.P. 2,571,333.

U.S.P. 2,570,719 (26.4.49; 9.10.51). H. W. Rudel and A. D. Kirshenbaum, assrs to Standard Oil Development Co. Foaming in lubricating compositions is suppressed by adding 0·0001 to 0·01 wt-% of a compound of general formula



wherein R = C_{1-4} alkyl; R_1 = H, alkyl or aryl; x is an integer sufficient to give a mol. wt. of <300.

U.S.P. 2,572,429 (25.11.49; 23.10.51). K. D. Ashley and S. Mason, assrs to American Cyanamid Co. Soap composition consisting essentially of Al salt of a mixture of 1 to 20 wt-% of dimerized polyunsaturated C_{18} fatty acids and 99 to 80% monomeric C_{12-22} fatty acid. V. P. P.

Bitumen, Asphalt, and Tar

1170. Centrifuge method for analysing road and building asphalts. D. C. Broome and G. E. King. *Rds & Rd Constr.*, Aug. 1951, **29**, 216–17.—The need for a rapid method of analysing asphalt mixtures suitable for general application is remarked, and details are presented of equipment developed for this purpose at the Central Laboratories of the Limmer and Trinidad Lake Asphalt Co. This comprises a plate-type centrifuge, carrying six 500-ml tubes, and driven by a 3 to 6 variable h.p. motor. The method of operation is outlined, duration and accuracy is discussed and compared with Method BAI of B.S. 598; 1950. Limits of repeatability, reproducibility, and methods of reporting are covered. J. G. H.

1171. Rapid method of analysis for bituminous road materials. A. R. Lee, C. M. Gough, and E. H. Green. *Rds & Rd Constr.*, May 1951, **29**, 128–30.—Details are presented of the rapid methylene chloride method developed at the Road Research Laboratory for analysing a sample of bituminous road mixture, by means of which the tar or bitumen content is determined within 30 to 90 min. A modification of the method is described which enables the grading of a wearing-course material, as well as the binder content, to be determined by a single operator within 2 to 3 hr. A further modification necessary is also described for determining binder content when fine limestone fillers or hard natural asphalts are employed. J. G. H.

1172. Asphalt, a colloidal material. R. N. Traxler and J. W. Romberg. *Industr. Engng Chem.*, 1952, **44** (1), 155–8.—General article on the physical and colloidal properties of asphaltic materials. Seventeen references. E. J. C.

1173. Patents. U.S.P. 2,570,185 (18.4.47; 9.10.51). P. H. Aldrich, assr to Minnesota Mining and Manufacturing Co. Wetting and anti-stripping additive for bitumen prepared by heating together a tertiary-carbinoxy polyamino silane and an amine having an $-NH_2$ group attached to a chain of 6 to 18 C atoms.

U.S.P. 2,571,956 (12.10.49; 16.10.51). J. C. Showalter, assr to Standard Oil Development Co. Composition for removing asphalt coatings consisting in vol-% of an aromatic hydrocarbon b.p. 300° to 500° F (25 to 75), hydrophilic alkali-metal

petroleum sulphonates of mol. wt. 325 to 400 (5 to 33), lub oil of visc 75 to 300 S.S.U/100° F (5 to 50), hydrophobic alkali-metal petroleum sulphonates of mol. wt. 400 to 500 (5 to 12). V. P. P.

Special Hydrocarbon Products

1174. Permeability of waxed paper. A. Kreyenbuhl. *Rev. Inst. franç. Pétrole*, 1952, **7**, 15–20.—Moisture-vapour permeability (P) (g/m²/24 hr) was measured on a number of paraffin and microcrystalline wax-coated papers available in France. "Tropical" test conditions (100° F, 92% humidity) were used employing TAPPI procedure of increase in wt of anhyd $CaCl_2$. Effect of creasing was measured by ratio permeability uncreased (P_1)/permeability creased (P_2) (max possible = 1). Paper is considered good if $P < 15{\cdot}5$ and if P_1/P_2 is 0·7 or over. Laminated paraffin-waxed papers best fulfil these requirements. V. B.

1175. Carbon black differentiation by electrical resistance of vulcanizates. J. E. McKinney and F. L. Roth. *Industr. Engng Chem.*, 1952, **44** (1), 159–63.—Apparatus and technique are described for measuring resistivity of GR-S vulcanizates. Results obtained varied considerably with type of carbon black present in the vulcanizate. E. J. C.

1176. Patents. U.S.P. 2,569,595 (8.11.47; 2.10.51). L. M. Adams, P. L. Brandt, R. J. Lee, and F. T. Wadsworth, assrs to Pan-American Refining Corp. In preparing drying oils from clay polymer, the polymer is distilled to separate a fraction of visc 200 to 1000 S.S.U/210° F which is fractionally distilled at 5 to 10 mm Hg pressure to separate a drying resin as bottoms and a drying oil as distillate, the latter being treated in naphtha solution with conc H_2SO_4 to remove coloured bodies and reduce the iodine value.

U.S.P. 2,570,990 (26.4.44; 9.10.51). J. A. Southern, L. J. Roth, F. J. Licata, and J. Cunder, assrs to the U.S.A. as represented by the Secretary for War. Soap-type gelling agent forming with a volatile hydrocarbon fuel an incendiary gel comprising 50 to 75 wt-% Al oleate, 25 to 50 wt-% Al stearate, *ca* 1% oxy-aromatic anti-oxidant, and 4 to 10% Na oleate containing a minor amount of Na stearate.

U.S.P. 2,570,023 (13.3.48; 2.10.51). C. S. Carlson and M. W. Swaney, assrs to Standard Oil Development Co. Parasiticidal oil emulsion concentrate comprising a highly aromatic, synthetic, steam-cracked (at 1100° to 1500° F) paraffinic gas oil fraction (sp. gr. 1·00 to 1·125; b.p. 625° to 775° F, kauri butanol value 80 to 104; Me_2SO_4 value 14 to 100) and a water-soluble emulsifier.

U.S.P. 2,570,050–1 ((*a*) 26.7.45; (*b*) 5.11.45; 10.2.51). L. T. Eby, assr to Standard Oil Development Co. Beta (tertiary-alkyl thio) ethanols prepared by condensing tertiary alkyl mercaptans and alkylene oxides, and insecticidal compositions containing same.

U.S.P. 2,572,574 (25.7.50; 23.10.51). A. H. Schlesinger and D. T. Mowry, assrs to Monsanto Chemical Co. Herbicidal compositions containing as the chief toxic ingredient 3-(thiocyanomethyl) thianaphthene. V. P. P.

Derived Chemical Products

1177. Petroleum chemicals and paint. Anon. *Paint Manfr*, Jan. 1952, **22** (1), 22.—An abstract of paper presented by F. Chapman at a recent meeting of the London section of the Oil and Colour Chemists Association.

*iso*Propyl alcohol was first produced direct from propylene obtained as a refinery by-product in the early 1920s, this marked the beginning of the petrochemical industry. The Catarole process is discussed. A heavy naphtha is catalytically cracked at 650° to 700° C, giving approx equal quantities of a gaseous and a liquid product. Products isolated from the gaseous fraction are ethylene, propylene, butanes, butenes, and butadiene. The liquid fraction is almost entirely aromatic. *iso*Propanol and its derivatives and other solvents produced by the Catarole process are considered, particularly with regard to their use in the paint industry.

Resins obtained from the polymerizable portion of the alkylbenzene fraction are also considered, and also the use of styrene fractions in varnishes, etc. A review of the ensuing discussion is included. D. K.

1178. Surface active alkyl aroyl sulphopropionates. G. W. Hedrick, W. M. Linfield, and J. T. Eaton. *Industr. Engng Chem.*, 1952, **44** (2), 314–17.—Preparation and wetting properties of a new series of surface-active agents of the type

$$\mathrm{Ar{-}CO{-}A{-}COOR}$$
$$\diagup$$
$$\mathrm{SO_3M}$$

are reported. Wetting properties of sodium salts of *sec*-butylbenzoylsulphopropionic and alkyl *iso*propylbenzoylsulphopropionic acids are tabulated. E. J. C.

1179. Patents. U.S.P. 2,572,251 (31.10.49; 23.10.51). A. De Benedictis, S. A. Ballard, and G. W. Hearne, assrs to Shell Development Co. Ether formation during hydrolysis of saturated $C_{<8}$ aliphatic halides with aqueous alkali is prevented by adding a water-immiscible hydrocarbon solvent.

U.S.P. 2,569,671 (16.7.48; 2.10.51). W. B. Hughes and J. Newcombe, assrs to Cities Service Oil Co. Crude alcohol solutions containing carbonyl and acetal impurities are purified by hydrogenating at 100° to 250° C/500 to 3000 p.s.i.g. in presence of a hydrogenation catalyst and 0·005 to 1% of sulphuric or phosphoric acid.

U.S.P. 2,571,208 (17.12.49; 16.10.51). L. E. Craig, assr to General Aniline & Film Corp. Production of 1 : 2-epoxy *cyclo*-octane by reacting *cyclo*-octene at $>20°$ C with a solution of peracetic acid.

U.S.P. 2,572,238 (20.11.48; 23.10.51). S. A. Ballard, K. E. Furman, and H. de V. Finch, assrs to Shell Development Co. Direct conversion of aliphatic primary mercaptans to alkali-metal salt of an aliphatic carboxylic acid by contacting with a molten alkali metal hydroxide in presence of tungsten and nickel sulphides at not above 485° C.

U.S.P. 2,569,644 (18.10.44; 2.10.51). F. B. Stilman, assr to the U.S.A. as represented by U.S. Atomic Energy Commission. An aliphatic or alicyclic compound containing 2 to 7 C, >1 F, >1 Cl, and >2 H atoms per mol is heated in liquid phase at 140° to 350° C in contact with metallic copper and the product separated and treated with SbF_3, AgF_2, CoF_3, or MnF_3 to replace at least part of Cl by F.

U.S.P. 2,572,564–5 (21.12.48; 23.10.51). C. M. Himel and L. O. Edmonds, assrs to Phillips Petroleum Co. (*a*) Preparation of alkyl thiocyanates by reacting an alkyl sulphenyl halide with HCN or an alkali or alkaline earth metal cyanide. (*b*) Tertiary-alkyl sulphenyl thiocyanates.

U.S.P. 2,572,567 (12.12.49; 23.10.51). C. M. Himel and L. O. Edmonds, assrs to Phillips Petroleum Co. Preparation of organic sulphenyl thiocyanates by reacting a thiosulphenyl halide with a metal cyanide.

U.S.P. 2,570,083 (14.4.47; 2.10.51). E. F. Wadley, assr to Standard Oil Development Co. Preparation of thiophenes by heating butadiene, isoprene, or pentadiene with H_2S in a SiO_2-lined reaction vessel at 500° to 650° C. V. P. P.

Coal, Shale, and Peat

1180. Styrene–ethylbenzene–diethylene glycol system. Ternary saturation-equilibrium diagram. M. G. Boobar, P. M. Kerschner, R. T. Struck, S. A. Herbert, H. L. Gruver, and C. R. Kinney. *Industr. Engng Chem.*, 1951, **43** (12), 2922–4.—Heat-sensitive, readily polymerizable, unsaturated compounds present in coal tars might be recovered by solvent extraction. Styrene–ethylbenzene system was used to simulate the unknown system, and experiments revealed that diethylene glycol was the most selective solvent for styrene.

Ternary data are tabulated and plotted for 25° C at 1 atm. E. J. C.

1181. Refining of middle fractions of primary tar from Budagovsk sapropelites. N. I. Shuikin and E. A. Timofeeva. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1951, 728–32.—(Cf. Abs. 2420—1951.) Middle fraction (170° to 350° C) containing 44% unsaturated, 8% aromatic, 8% cyclane, 30% alkane was treated (450° C) with acid-activated kaolin (analysis given). Satisfactory results were obtained (but not with $AlCl_3$), product (after alkali wash) yielding (% on feed) 31·6 gasoline (200° C) of 0.N. 63, 44·6 kerosine, and 2·8 residue. Gasoline and kerosine had high aromatic contents (37 and 44% respectively); by such treatment of middle fractions overall gasoline yield (calc on tar) is increased 7%. Analyses of feed and products are given. Clay can be regenerated (air at 500° C); no loss in activity was noted after ten cycles. V. B.

1182. Correlation between coking conditions, tar yields, and properties. P. Damm. *Erdöl u. Kohle*, 1951, **4**, 765–70. In low-, medium-, and high-temp carbonization processes, production of tars is governed by the nature of coal, type of furnace, and operating conditions used. Yields of primary tar, produced at temp up to 550° C, vary from 12% (with a phenol content of 45%) for young, open-burning coals to 1·5%, (with no phenols) for older lean coals. Primary tars are usually decomposed further, yields and properties of final tar products being determined by the reaction temp. At sufficiently high temp the nature of tar produced is independent of the type of coal and process employed. Various German coals are reviewed for tar formation, total bitumen content, and composition. Combustion time and type of chamber, nature of heating media and fusion properties of coal used are important factors in tar manufacture. Description of tar production in present coking processes is given; such processes are primarily designed for producing good coke, and any measures to improve the tar by-products must be compatible with that aim. The only economical modifications fulfilling these conditions are those affecting design of gas-collector installations in coking processes. P. V.

1183. Derivatives from the low temperature carbonization of coal. II. Anon. *Industr. Chem.*, 1951, **27**, 545–50.—At Bolsover plant of British Diesel Oil & Petrol Co. large quantities of effluent liquor containing 1 to 5% phenols are treated with butyl acetate in an extraction column, extraction being virtually complete at a butyl-acetate-to-liquor ratio of 1 : 8. Products are separated by dist, and butyl acetate recycled. Chlorinated phenols, *e.g.*, dichlorphenol, are manufactured; also trixylenol phosphate, a plasticizer for polyvinyl chloride. A. C.

Miscellaneous Products

1184. Plastics versus metals in bearings. R. H. Warring. *Mech. World*, Jan. 1952, **131** (3390), 27.—Plastic bearings have given satisfactory service in rolling mills and automobile and aircraft engines. They are resistant to the action of suds, oils and petrol, grease, graphite, and most mild acids and alkalis. Adequate supply of lubricant for cooling is essential owing to low thermal conductivity. In cases where the bearing is working in a solution, the solution itself may be adequate. Water or aqueous solution may be used as a lubricant. Types of bearings are discussed. With pressure lubrication at high speeds, friction may be reduced to a figure comparable with that of roller bearings. Properties of plastics suitable for bearings are given. T. T.

1185. Less familiar metals of commercial importance. R. A. Lubker. *Mech. Engng*, Jan. 1952, **74** (1), 3.—The availability, production processes, properties, alloys, cost, and uses of twenty metals which are relatively uncommon but of appreciable or potential industrial importance are discussed. T. T.

1186. Toughened glass. A survey of properties, manufacture and application. H. D. Hendrick. *Auto Engr*, 1952, **42** (549), 9.—Toughened or "Armoured" glass has been developed to withstand severe service conditions, and has been adapted for use in a wide range of industries. The properties of toughened glass are discussed, and the manufacturing process described. The glass must be cut to shape, drilled, etc., before toughening, and cannot be worked afterwards. Limitations as to size and position of holes are given. T. T.

1187. Silicones in wax polishes. T. A. Welch. *Soap Sanitary Chem.*, **28** (1), 117.—Silicones are recommended for use as an addition to conventional wax polish for the advantages of their chemical and thermal stability and water repellency. By their incompatibility in the wax, a high degree of slip can be given without softening the wax or interfering with durability. Dimethyl and diethyl silicone oils are discussed. Each type has an optimum visc, and such properties as gloss, durability, ease of polishing, smearing during application are compared for the two types. Simple formulæ adding silicone oils to car polishes, cleaner polishes, and furniture polishes are given. N. W. G.

1188. Shampoos—pretesting surface active agents. H. A. Shelanski. *Soap Sanitary Chem.*, Jan. 1952, **28** (1), 32.—Following legal action by the U.S. Food and Drug Administration against shampoos causing eye injuries, tests on surface-active agents were made by the Division of Pharmacology. As a class, the non-ionics gave the least irritation, then anionics next, with cationics most irritating. Individual members of the different types show variations in their properties, and it was concluded that, with evaluation of the ingredients, satisfactory shampoos could be made for all classes. The tests should cover eye-irritation properties, skin-irritant capacity and sensitization properties, and acute oral toxicity. Recommendations for methods of testing are also included. N. W. G.

1189. 400,000 tons of sulphur a year from oil and gas. A. L. Foster. *Petrol. Engr*, Nov. 1951, **23** (11), C3–4.—A survey of projected sulphur-recovery units in the U.S. shows that half the million tons world deficit of sulphur may be made up by 1953. Nearly 400,000 tons/year is the estimated output of oil and gas company units, and another 500,000 tons annual capacity is envisaged from deposits in the Mississippi delta area. Within 2 years an additional 1½ million tons annual capacity should be available which will be more than required to make up the present deficit. E. K. J.

1190. Tread wear of tyres. J. Mandel, M. N. Steel, and R. D. Stichler. *Industr. Engng Chem.*, 1951, **43** (12), 2901–8.—The tread-wear characteristics of several rubbers and carbon blacks were investigated together with other variables. E. J. C.

1191. Furane cements. R. B. Seymour and R. H. Steiner. *Chem. Engng*, 1951, **58** 268.—Polyfurfuryl alcohol resin with pure carbon filler is resistant to acids and alkalis up to 375° F according to laboratory tests and some field tests. A graphical form is used to represent the 200 applications for which it has been tested. H. D.

1192. Patents. U.S.P. 2,570,094 (28.3.50; 2.10.51). H. W. Bradley, assr to E.I. du Pont de Nemours and Co. Producing a film-forming thermoplastic composition by reacting a polysulphonyl choride of a polymerized C_{2-8} olefin in aq alcohol with a polyethanolamine, polypropanolamine, or morpholine.

U.S.P. 2,572,572 (5.2.45; 23.10.51). D. T. Mowry and R. B. Seymour, assrs to Monsanto Chemical Co. Copolymer of ar- *cyclo*hexylstyrene and styrene.

U.S.P. 2,572,185 (17.1.47; 23.10.51). H. D. Noether and E. P. Irany, assrs to Celanese Corp of America. Copolymers of styrene and SO_2.

U.S.P. 2,571,883 (28.10.48; 16.10.51). G. E. Hulse, assr to Hercules Powder Co. Homopolymer of 2-methylene-1 : 3-propylene dichloride.

U.S.P. 2,569,540–1 ((*a*) 4.1.49; (*b*) 19.10.49; 2.10.51). H. E. Selby, assr to Bishop Manufacturing Corp. (*a*) Insulating composition which flows into a homogeneous body when disposed in overlapping laminations comprises up to 50% of a semi-rigid polyethylene; 5 to 20% of a sulphur-vulcanizable rubbery copolymer of *iso*butylene and a diolefin in ratio 98 : 2; 9 to 65% of an *iso*butylene of average mol. wt. 60,000 to 75,000, and 1 to 20% of a resinous tackifier for imparting flow and cohesiveness. (*b*) Insulating composition which is thermoplastic, extrudable, and resistant to shattering at <0° F comprises 24 to 28 parts of polyethylene (mol. wt. *ca* 20,000); 14 to 30 parts of an *iso*butylene homopolymer (average mol. wt. 40,000 to 60,000), 7 to 14 parts of a rubbery copolymer of *iso*butylene and a diolefin in ratio 98 : 2 and ½ to 2 parts of a lubricant.

U.S.P. 2,570,353 (25.5.48; 9.10.51). R. M. Leekley, assr to Time Inc. Printing ink consisting essentially of a pigment suspended in a solution of zein and containing 2 to 10% of a lubricating and wetting composition consisting of 70 to 90% light mineral oil b.p. *ca* 400° F and 10 to 30% of a sulphated vegetable oil or sulphonated mineral oil.

U.S.P. 2,572,805 (17.10.47; 23.10.51). J. C. Harris and M. Kosmin, assrs to Monsanto Chemical Co. Detergent composition comprising a condensation product (*a*) of 1 mole of tall oil with 3·4 to 34 moles of ethylene oxide and a condensation product (*b*) of 1 mole of a C_{6-20} aliphatic mercaptan with 1 to 40 moles of ethylene oxide, (*a*) and (*b*) being in the wt ratio of 1·5 to 9 : 1. V. P. P.

CORROSION

1193. Corrosion and its control. M. E. Parker. *Oil Gas J.*, 7.1.52, **50** (35), 89; 14.1.52, **50** (36), 124; 21.1.52, **50** (137), 114; 28.1.52, **50** (38), 371; 11.2.52, **50** (40), 137.—Pt 41 of this series deals with low-temp hydrogen attack of steel. This takes the form of blistering, cracking, or loss of ductility, and is associated with electrolytic corrosion in the presence of water.

Detection is difficult and time-consuming; two methods are given.

Pt 42 deals with high-temp hydrogen attack on steel. Iron carbides present in steel react with hydrogen to form methane, which is trapped, thus building up very high localized pressures. Eventually tensile strength and ductility are seriously affected. Process modification, use of alloy steels and of clad metal are methods of combating results of hydrogen attack.

Pt 43 discusses use of ammonia for combating acid corrosion in refineries. Advantages include fact that it may pass through part of the stream as vapour, and condense at point where condensed acidic water is causing corrosion; also its volability precludes formation of strongly alkaline solutions.

Liquid ammonia can be directly injected on downstream side of stills and cracking units.

A relatively small amount of ammonia is sufficient to reduce hydrogen sulphide corrosion to vanishing point.

Pt 44 deals with metal linings for corrosion resistance. Size of sheet available and size of vessel openings will determine maximum unit of application.

"Plug," strip, and stud welding techniques for attachment are discussed, together with method of avoiding contamination.

Pt 45 deals with passivators and inhibitors. It is thought that passivity occurs when at the surface of the passive metal some kind of film–metal oxide, oxygen, etc.—forms.

Inhibition is associated with films of greater thickness, such that actual obstruction to physical penetration of damaging ions is offered. Inhibitors can be classified as anodic or cathodic. Phosphates, chromates, and silicates are typical anodic inhibitors; carbonates and bicarbonate act in water, as cathodic inhibitors. G. A. C.

1194. How to combat heat-exchanger corrosion. A. R. Dyer. *Oil Gas J.*, 4.2.52, **50** (39), 69.—Types and combination of types of corrosion, causing failure of carbon steel and admiralty tubes in water-service tube and shell condensers and coolers are listed and described. And also corrosion of carbon-steel tubes in steam service.

In oil service sulphur compounds, hydrochloric, and some organic acids are main corrosives.

Use of aluminium, duplex, or bimetal tubes, and of protective coatings, will help to combat corrosion. G. A. C.

1195. Fretting corrosion in aircraft and aircraft accessories. A. E. Rahm and H. J. Wurster. *Lubr. Engng*, Feb. 1951, **7** (1), 22–8, 40.—The historical background of "fretting corrosion," the rapid corrosion occurring between contacting metal surfaces when subjected to slight vibratory motion, is outlined, and existing data on the subject are summarized. Details are presented of an investigation with helicopter rotor-head main thrust bearings which had suffered severe damage from fretting corrosion. Certain design details were changed, as was the type of lubricant used and the method

of surface finish, superfinish being here substituted for the normal commercial finish. A special friction oxidation testing fixture was developed, being a modification of the "Fafnir" bearing-testing apparatus, and details of procedure and test runs on this equipment are presented. The results obtained indicate that while a combination of the best factors in bearing design, surface finish, and lubrication will lead to an appreciable increase in operational life, these do not in themselves represent a solution to the problems. J. G. H.

1196. Corrosion of steel in molten sulphur. A. Dravnicks. *Industr. Engng Chem.*, 1951, **43** (12), 2897–900.—The experimental procedure and results obtained in testing the corrosive action of molten sulphur at 200° to 450° C on steel are reported. A mechanism is proposed to account for the observed results. E. J. C.

1197. Ultrasonic equipment testing in the petroleum industry. D. J. Evans. *Oil Gas J.*, 4.2.52, **50** (39), 70.—The use is described of the ultrasonic instruments "Reflectoscope" and "Audigage" for detection of hidden flaws in equipment, and measurement of metal thickness.

The Reflectoscope operates on the "pulse technique" a short, high-frequency pulse of ultrasonic energy being projected into the material under test and reflected from opposite surface or from a defect, as opposed to the continuous wave generated in the resonance method. The process is rapidly repeated and appears as an image with continuous lines and marks on the cathode-ray valve face. Large pieces of equipment can be inspected for fatigue cracks while in place.

The Audigage measures thickness by determining frequency at which resonance of the ultrasonic waves occur, and can measure thicknesses varying from $\frac{1}{16}$ inch to 12 inches in steel, brass, and aluminium. The instrument consists essentially of a high-frequency electronic oscillator, a quartz crystal to convert energy into pressure waves, and a means of detecting frequency at which resonance condition is set up. The instrument is used to determine extent of corrosion. G. A. C.

1198. Radio-isotopes aid corrosion research. J. M. Swartout. *Petrol. Engr*, Apr. 1950, **22** (4), C31.—The investigations are concerned with minute differences on surfaces of metals. Virtually every exposed metal presents a non-homogeneous surface that may influence ways in which corrosion occurs. It is believed it may be possible to locate sensitive spots on metallic surfaces and to determine the effect of certain salts in decreasing the resistance to corrosion. Corrosion in high-pressure condensate wells, the effect of adsoption of certain gases at varying pressures on metal reactivity, and the effectiveness of fifty different chemicals as corrosion inhibitors is also investigated. In some cases corrosion has been retarded by 90%, the best results being obtained with fatty acids or amines. When a thorough knowledge of metal surfaces has been obtained, it may be possible to perfect a mixture as a more efficient inhibitor than one chemical alone. E. S. L.

1199. Abrasion resistance of sulphuric acid anodic films on aluminium and its alloys. R. C. Spooner. *Canad. J. Tech.*, 1951, **29**, 479–91.—A total of six aluminium alloys were anodized in sulphuric acid, and after water-sealing the abrasion value of the anodic coatings produced was determined using the standard ASTM abrasive-blast technique. Determination of the effect of five process variables, namely anodizing time, sealing time, air ageing, current density, and electrolyte temp, was made. Increased film thickness produced by lengthening anodizing time, rising current density, or lowered electrolyte temp augmented the abrasion value. Increasing periods of water-sealing or air ageing of unsealed coatings lowered the abrasion values. Increased current density increased the abrasion coefficient. Only slight differences were found in the abrasion value of anodic films of 99·99%, 99·76%, 2S, and 3S aluminium alloys. A slight increase was determined with 50S, while 24S considerable decrease was observed. S. B.

1200. Nature and use of petroleum base rust preventives. H. B. Carpenter. *Lubr. Engng*, Aug. 1951, **7** (4), 174–7.—The general functions of rust preventives are indicated, and the special characteristics of petroleum-base preventives are noted. The four types—plastic, fluid, thin film, and solvent—are enumerated with their distinctive

properties and fields of application. The use of humidity cabinets, salt-spray equipment, and weatherometer in the conduct of laboratory tests for the prediction of service life is described, together with preliminary cleaning of the surface to be treated, general methods of application, and precautions to be observed in the treatment of special classes of equipment. J. G. H.

1201. Liquid and vapour corrosion inhibitors. H. A. Baker and W. A. Zisman. *Lubr. Engng*, June 1951, **7** (3), 117–22.—Post-war research at the Naval Research Laboratory on corrosion inhibitors for non-aqueous systems, mainly concerned with the nature of soaps and of ammonium salts of high-mol.-wt. acids, the existence and structure of micelles in oils, the structure of inhibitory films, and the properties of vapour-type rust inhibitors are reviewed. J. G. H.

1202. Silicates in detergents. E. A. Robinson. *Soap Sanitary Chem.*, **28** (1), 34.—A review of recent literature on the use of silicates with various detergent formulæ to prevent corrosion of metals. A special case is the corrosion of aluminium, for which 22% of disilicate on the weight of soda ash or 30% on the weight of trisodium phosphate will control corrosion at all concentrations at temp up to 180° F. Practical examples are quoted for prevention of corrosion, with degreasing of military equipment, with bakery pans, degreasing of canned meat, iron, brass, and copper piping, dish-washing machines, dairy fixtures, vitreous enamel, and home washing machines. It is concluded that soluble silicates, with the ratio 2 or more parts of silica to 1 part of sodium oxide, will inhibit or retard the corrosion of light metals or alloys. N. W. G.

1203. Investigations on underground corrosion. K. R. Butlin, W. H. J. Vernon, and L. C. Whiskin. *Fluid Handling*, Jan. 1952 (24), 21–3. (*Symp., Iron & Steel Inst., Dec.* 1951.)—Results of field and experimental pipe tests are given on iron and steel with and without coatings, and on asbestos, lead, copper, and alkathene pipes. D. H.

1204. Tests on the corrosion of buried iron and steel pipes. J. C. Hudson. *Fluid Handling*, Jan. 1952 (24), 13–16. (*Symp., Iron & Steel Inst., Dec.* 1951.)—Conditions of exposure on five test pipes are given. The resistances of the non-metallic coatings at one of the sites are compared after five years. D. H.

1205. Graphite ground anodes protect high-pressure gas lines. A. W. Peabody. *Oil Gas J.*, 28.1.52, **50** (38), 374.—The utilization of cathodic protection on 38 miles of gas line ranging in size from 2 to 20 inches, carried out by Rochester Gas and Electric Corporation, U.S.A., is described.

The older original sections of the line are fifteen years of age, newer portions but recently completed, so that rapidly increasing numbers of corrosion leaks had to be checked and corrosive action prevented elsewhere.

Several corrosive conditions were present in the pipeline network, needing four ground beds using sixty-nine 2 × 30-inch graphite ground anodes and coke-breeze backfill. Additionally, a large section of abandoned pipeline was utilized as another ground connexion, but results were not highly successful. At a water crossing the line was completed, insulated from both land-side sections. Power to activate the several ground beds supplied by rectifiers. G. A. C.

1206. Cathodic protection of "Presidente Peron" gas-line. F. F. Blanco. *Boletin Inst. Sudamericano Pet.*, 1951, **3**, 135–55.—This pipeline covers 1605 km from Comodoro Rivadavia to Buenos Aires. More than 900 km have now been provided with cathodic protection against corrosion. Soil conditions vary considerably over this distance, resistances between 1000 and 4000 ohms/cm³ or higher being encountered. Different types of protective equipment are installed for different soil conditions, magnesium-alloy anodes being largely used. All information collected is recorded in central station, which repeats measurements periodically and adjusts potentials as necessary. A. C.

1207. Patents. U.S.P. 2,572,301 (27.5.47; 23.10.51). R. A. Baker, assr to Socony-Vacuum Oil Co. Corrosion of steel surfaces in contact with hot caustic alkali solutions containing mercaptans is prevented by adding 0·1 to 1·0 wt-% of alkali-metal phosphate.

U.S.P. 2,571,739 (28.10.49; 16.10.51). G. A. Marsh, assr to Pure Oil Co. Corrosion of metals by the action of a mixture of H_2S, air, and water is inhibited by adding a partially water-soluble $\alpha\beta$-unsaturated aldehyde. V. P. P.

Engines and Automotive Equipment

1208. Diesel engines for large tankers. I. Wans. *Motor Ship*, Jan. 1952, **32** (382), 387.—Discussion of proposed geared installation for a vessel with a machinery installation of 14,000 s.h.p. In view of advantages of multi-engine propulsion, consideration should be given to this type of installation when considering propelling machinery for tankers of 26,000 tons d.w.c. and above. Present power requirements for tankers of this size suggest that a total of 12,000 to 14,000 s.h.p. is needed. A 40% saving in wt is estimated by adoption of a medium-speed multi-engine installation instead of a large, slow-speed, direct-reversing engine of the same power. Each engine for a multi-engine installation, on the lines of that described, would be a four-stroke, pressure-charged, unidirectional unit with a cyl dia of 17 inches and a speed of 435 r.p.m. Under these conditions the rating would be conservatively fixed at 108 p.s.i. b.m.e.p., giving a power of 244 h.p/cyl. A diagram is given to compare the overall dimensions for one slow-speed engine or a multi-engine installation for each shaft. U. M.

1209. Marine gas turbine in M.V. "Auris". Anon. *Engineer*, 1952, **193**, 168–9.—A gas-turbine alternator unit has been installed in place of one of the four diesel engines on Anglo-Saxon's tanker M.V. *Auris*. Main object was to prove reliability of new prime-mover rather than improve thermal efficiency. Unit designed for max high-pressure turbine inlet temp of 1200° F and power output of 860 kW at alternator terminals. On trials this temp was 920° F for 300 kW output, and final exhaust temp, after low-pressure turbine and heat exchanger, was 360° F. Tanker speed with gas turbine set only was 7 knots; using gas turbine and three diesels speed was 9·2 knots. One round voyage of forty-two days completed without incident. Gas turbine now uses boiler fuel of 1500 sec Red. I visc at 100° F. Ash content of fuel reduced to 0·02% by passage through centrifugal purifier and clarifier units in series. A. C.

1210. Internal combustion engine pressure diagrams. W. P. Mansfield. *Mech. World*, 14.12.51, **130** (3387), 543.—The diagrams obtained on the screen of the cathode-ray oscillograph type of indicator are of little value in the determination of I.H.P. and gas-pressure torque because the ordinates and abscissæ are not accurately proportional to pressure and time, although instruments capable of development are available. In the Farnborough balanced-pressure type of indicator, the disk valve, acting as a switch in the L.T. circuit, is in communication with the combustion chamber, and fouling of the contact surfaces produces scatter of points on the diagram.

Greater accuracy is possible with an indicator in which the movement of a small disk is indicated by means of an electro-magnetic pick-up and an oscillograph. This instrument is unaffected by slight fouling, and can be checked easily after use. The inability of this indicator to respond satisfactorily to high-frequency pressure oscillations makes it unsuitable for the study of detonation and diesel knock. Until recently diagrams were obtained by feeding the output of a Sunbury disk-valve unit, together with the output of a degree-scale pick-up unit, to the amplifier of a Sunbury engine indicator, the resultant diagrams for a series of pressures being photographed and the points plotted. The method was abandoned owing to the length of time required to produce a complete indicator diagram. An indicator was developed in which the sparks of a Farnborough recording unit were controlled by a thyraton control unit utilizing the output of a Sunbury disk-valve unit. The diagrams produced with this instrument showed no discrepancies when compared with diagrams produced by the normal Sunbury disk-valve method. Pressure calibration and T.D.C. lines are marked on the diagram. Corrections for the response delay are discussed. An alternative arrangement with the electro-magnet replaced by a condenser is described. This unit is less sensitive to shock. An indicator with a balanced diaphragm is described and its disadvantages mentioned. Bibliography of seven references is appended. T. T.

1211. New knockless engine. A. L. Foster. *Petrol. Engr*, Dec. 1950, **22** (13), C34.—A description of an engine, which claims to be free from the influence of octane and cetane nos, and relatively insensitive to the volatility of the fuel, is given. This is accomplished by the production of a swirling action in the cyl (by which no pocket of fuel–air mixture is held at any point to reach the auto-ignition temp to produce knock) and correct relative positions of injector nozzle and spark plug. This engine is also claimed to have the power output of the gasoline engine combined with the fuel economy of the diesel engine. The ranges of knock-free operation are given with a variety of fuels, including alcohol, tractor fuel, etc. E. S. L.

1212. Maintenance of internal combustion engines. Filtration of air and oil. P. H. Moore. *Petrol. Engr*, June 1950, **22** (6), C7–12.—Tests were conducted on a four-cyl, side-valve, four-stroke gasoline engine to discover the effect of filtered air and oil. The dust was artificially created, and trials were carried out with no filters, with air filter alone, and with air and oil filters. Wear was ascertained by either measurement or wt, and while both air and oil filtration reduced the wear, it was found that in the upper regions of the engine (piston-top land, piston-rings, cyl bore, valve stem) air filtration had the greater effect on reducing wear, and the same was noted with the main bearing and big-end bearing, indicating that dust in the air penetrates to the sump easily. In the case of the crankshaft journal oil filtration has the greatest effect. Oil consumption and combustion-chamber deposits are reduced considerably by both filters. In the case of valve-guide wear there was some discrepancy due to practical difficulty. Surface profile graphs are presented. E. S. L.

1213. Selection of electric motors. J. Benish. *Petrol. Engr*, Dec. 1950, **22** (13), C7–12.—A general discussion on factors to be considered when selecting electric motors, *i.e.*, load characteristics, voltage, types in relation to operating conditions, h.p., and economics. The operating characteristics of A.C. and D.C. motors are discussed and illustrated graphically. Synchronous motors should be used for more than 50 h.p. at low speeds and for 500 h.p. at any speed. The sources giving standards necessary to comply with for safety, etc., in the U.S. are given. Relative prices of various motors are tabulated. E. S. L.

1214. More notes on crankcase explosions and their prevention. Anon. *Scientific Lubrication*, Sept. 1951, **3** (9), 17, 30.—Points discussed include composition of crankcase atm, secondary explosions, and dangers arising from overheated parts. Details are presented of an explosion-tube apparatus used to study the mechanism of crankcase explosions and to determine the inflammability properties of lubricating oils. Recent U.S. Navy tests are briefly summarized. J. G. H.

1215. Independent rear suspension. Potential advantages and requirements. D. Bastow. *Auto Engr*, 1952, **42** (549), 13.—Efficient design of independent rear suspension should result in a reduction in unsprung weight, absence of propellor-shaft torque, elimination of rear-end hops and shakes, and lessened rear-end steering effects. Rear brakes can be mounted inboard and cooled more easily, and a simple mechanical linkage can be used for operation. A car with I.R.S. should give a more comfortable ride, with a reduced tendency to roll. It is suggested that a new approach to frame design is required in order that the full potentialities of I.R.S. may be realized. T. T.

1216. Tyre testing. Some aspects in relation to vehicle behaviour. V. E. Gough and P. W. B. Jones. *Auto Engr*, 1952, **42** (549), 17.—The essential requirements of a tyre are listed, and it is stated that although pneumatic tyres meet these requirements in major respects, some compromise between several features is inevitable in a practical design. Road tests are necessary to determine to what extent a particular tyre gives satisfactory results. Cornering, skidding, comfort, effective rolling radius, tread wear, and the estimation of wheel load are discussed. There is a bibliography of eighteen references. T. T.

Safety Precautions

1217. The refiners' notebook. Anon. *Oil Gas J.*, 21.1.52, **50** (37), 119; 28.1.52, **50** (38), 391.—No. 106 in this series deals with gas explosions and quotes data taken from U.S. Bureau of Mines I.C. 7606 "Gas Explosions and their Prevention." Limits of inflammability, complex and non-uniform mixtures, flash point, temp, and pressure are among points discussed.

No. 107 discusses means to prevent explosions by addition of inert gas such as nitrogen, helium, carbon dioxide, steam, etc., to the combustible.

A graph shows possible and impossible inflammable mixtures. G. A. C.

1218. New method of tank fire fighting. Anon. *World Petrol.*, 1952, **23** (2), 44–5.—Injection of small quantities of compressed air at base of a burning tank creates turbulence which cools the surface. High API gravity crude fires require little foam, kerosine and high-flash fractions are extinguished in a few sec after injecting air. E. B.

1219. Sparks in the plant. D. Attaway. *Petrol. Engr*, Mar. 1950, **22** (3), C13.—A review is given of hazards of sparks in an industrial plant, precautions necessary for their control, and an indication of the relative number of fires caused by sparks from the following sources: (1) friction or impact; (2) welding; (3) electricity (including static); (4) smoke stacks; (5) engine exhausts; (6) smoking; and (7) pump packing. E. S. L.

1220. Do's and don'ts for well pullers. R. Sneddon, *Petrol. Engr*, Nov. 1951, **23** (12), B42.—Practices recommended for increasing safety and reducing the accident rate on well-pulling jobs are described. Some points are illustrated by means of photographs. C. G. W.

Miscellaneous

1221. '52 demand set at 7,939,000 brls daily. E. T. Knight. *Oil Gas J.*, 28.1.52, **50** (38), 222.—Tables show estimated demand and supply of petroleum products in the U.S.A., including domestic requirements for heating, transport, roads, etc., based on assumption that Persian supplies will not materialize during 1952. Tables also list cars, lorries, and buses registered in the U.S.A. G. A. C.

1222. Refining capacity scheduled for 3·5 per cent rise. R. B. Tuttle. *Oil Gas J.*, 28.1.52, **50** (38), 237.—Tables list active refinery construction projects for 1952, and refinery projects completed in 1951, showing owners and capacity rating. It is estimated that total capacity will be 7,360,000 b.d., an increase of 150,000 brl daily. G. A. C.

1223. World output up, despite Iranian loss. D. M. Duff. *Oil Gas J.*, 28.1.52, **50** (38), 232.—A table shows world crude oil production in thousands brls daily.

It is estimated that production for current year will be 12·5 million b.d.

Most of Iranian deficit in 1951 was made up by increased production by Kuwait (58%), Saudi Arabia (39%), and the U.S. (14%).

World production in 1951 showed an increase of 12·3% over 1950. G. A. C.

1224. World crude production up 12·4 per cent. Anon. *World Petrol.*, 1952, **23** (1), 30–1.—Despite loss of Persian oil, above-ground stocks increased 100 million brl in 1951. Total production was 4270 million brl. Output of major producers is tabulated. E. B.

1225. 4·4 per cent demand hike in 1952. R. E. Spann. *Refiner*, 1951, **30** (12), 79.—Petroleum Administration for Defense predict a total demand for U.S. petroleum in 1952 of 7,775,000 b.d., an increase of 330,000 b.d. or 4·4% over 1951 estimates. This is the smallest increase since 1949. The increase in military demand is expected to be

small, domestic demand 5·9% up, export 20·9% down. A peak in the demand is expected in the first quarter, after which home and export demand will decline. Supply of petroleum is expected to increase by 2·5%, and stocks will be reduced by 13,000 b.d. A. R. H.

1226. Field processing slated for big boost. R. B. Tuttle. *Oil Gas J.*, 28.1.52, **50** (38), 246.—Natural-gas processing-plant projects are listed, showing capacity rating, status, and completion schedule. It is estimated that input capacity increase should reach 1·3 billion cu. ft. daily during current year. G. A. C.

1227. Venezuela holds key to needed oil supplies. H. J. Struth. *World Petrol.*, 1952, **23** (2), 32–6.

1228. Petroleum deposits of Lake Maracaibo. A. Villafañe and R. Domingo Moros G *Boletin Inst. Sudamericano Pet.*, 1951, **3**, 119–34.—Detailed history, geological and production data concerning fields in Lake Maracaibo area of Venezuela. Total area covered is about 60,000 sq. km., largest fields being Lagunillas (25,000 hectares) and Tia Juana (17,400 hectares). Oldest fields (Cabimas, Mene Grande) date back to 1913. Cumulative production to end of 1950 was about 695 million cu.m. 63 million cu.m. being produced in 1950. Of the latter quantity, 50 millions were exported, 4 millions consumed in operations, and 9 millions refined. Refining capacity has doubled since 1949. Also produced were 7900 million cu.m. of gas. Details of pipelines, existing and projected, are listed; biggest is from Rio Ulé to Amuay refinery (227 km, 24 to 26 inches dia). 317 new wells were drilled in 1950, 306 being producers. A. C.

1229. Survey of oil fields. Anon. *Oil Gas J.*, 20.12.51, **50** (33), 335.—A comprehensive tabulated summary of the world's oilfields, giving for every country the principal companies operating; the name of each field and its date of discovery; the number of wells flowing, pumping, shut in, and drilling; daily average and cumulative production; the API gravity of the oil produced; and depth, name, and type of producing formation. J. C. M. T.

1230. How to estimate plant construction costs. Pt 1. Fundamentals of cost estimation. G. E. Brooks. *Petrol. Engr*, Mar. 1950, **22** (3), C7–10.—The first of three articles for plant engineer or chemist who does infrequent estimates is given. Methods of estimation: (1) outright guess; (2) preliminary estimate (from flow diagrams and plans to give idea of magnitude of project); (3) check estimate (at time of allocation of funds); (4) detailed estimate (usually used by firms soliciting contracts). Requirements for estimation are: (1) knowledge of things wanted that are not on flowsheet, of climate, labour, etc.; (2) experience of plants of size and type being estimated; (3) cost data—filing method to keep abreast of data is given; (4) system of correlation of cost data. Cost plotted versus a common variable gives exponential curve. Cost $= A$ (variable) ^{b}, where A is constant and (for many cases) $b = 0{\cdot}6$. Estimations of welded tankage and tubular heat exchangers are discussed. Recommended outline for estimate is given. E. S. L.

1231. How to estimate plant construction cost. Pt 2. Preliminary estimate. G. E. Brooks. *Petrol. Engr*, Apr. 1950, **22** (4), C21.—This estimate is often required to help decide between two or more possible processes as well as giving capital investment and anticipated annual returns. Approx costs only are required at this stage. Flow diagrams for each process are obtained and a tentative plot plan for each laid out, considering flexibility of operations, future development, land availability, fire hazards, etc. The plot plan should be superimposed on an existing map to facilitate estimation of cost of additional utilities and utilization of existing ancillaries. Three types of new constructions are considered, viz., expansion of existing facilities, new facilities in existing plant, and an entirely new construction on a new site. The Engineering News Record Construction cost index, and Marshall and Stevens Petroleum Equipment cost index are compared and criticized as sources of cost data. A preliminary estimate for the installation of a new two-stage crude unit with capacity of 10,000 brl per operating day (b.p.o.d.) on the atmospheric section, and 9500 b.p.o.d. on the vacuum section using the ENR index is presented fully. E. S. L.

1232. How to estimate plant construction costs. Pt 3. Check estimate. G. E. Brooks. *Petrol. Engr*, June 1950, **22** (6), C31.—The check estimate is to obtain more accurate and detailed estimates of cost for a project than were arrived at in the preliminary estimate. The costs are split up into: (1) direct and (2) indirect costs, the latter being subdivided into: (*a*) field construction expenses (temporary constructions, etc.) and (*b*) services (engineering and drafting, field supervision, etc.). Some data on individual costs (and their estimation when necessary) are given for items under (1), *i.e.*, for foundations, buildings, structural steel and timber, towers, etc., the use of graphs for various sizes, etc., being illustrated. The use of cost records is discussed, and summary sheets for a check estimate of two light-oil treating units are presented.
E. S. L.

1233. Development of heaters for petroleum and chemical processing. S. E. Nutter. *Petrol. Engr*, May 1950, **22** (5), C26.—A historical review from 1860 to 1950.
E. S. L.

1234. Standard Vacuum undertakes major expansion programme in India. Anon. *World Petrol.*, 1952, **23** (1), 35.—$35 million refinery with 19,000 b.d. capacity is planned for Bombay. Two ground geological parties are to be sent to E. India, the area containing the Digboi field, which produces 5300 b.d., 5·5% of India's requirements.
E. B.

1235. Use of scale models in the petroleum industry. M. Sittig. *Petrol. Engr*, Oct. 1951, **23** (11), C58.—Scale models of plant may be used in: (1) advertising and sales; (2) design; (3) construction; and (4) operation to give three-dimensional representation of layout. Numerous examples are detailed of the advantages to be gained by considering a model when blue-prints would be insufficient. The materials of construction which may be used are generally wood, plastics, or metal, and details of special materials are given in the article. The cost of models varies between 0·1 and 1·0% of the plant costs, but is usually justified by savings in costs of design, construction, and operation.
E. K. J.

BOOK REVIEWS

Petroleum Conservation. Ed. Stuart E. Buckley. Dallas, Texas: American Institute of Mining & Metallurgical Engineers, 1951. Pp. xix + 304. $6.0.

That conservation is a basically sound policy has become so deeply rooted in the oil producer's philosophy that it is not always realized what strenuous efforts had to be made to bring about the present outlook. It was necessary to advance technical arguments which would convince reasonable people and break the resistance of sectional interests. The battle was joined in the mid-1920s, and, as was to be expected in view of the predominant part played by the U.S. in the world oil production, was fought out on American terrain. As the technical picture cleared, the ideas advanced were gradually adopted by the industry, generally more readily outside the U.S. than in, until the policy became accepted.

The present volume is a memorial to Henry L. Doherty, the technical man whose pioneering efforts did more than anything else to bring the controversy into the open. It is the work of a number of contributors of very high standing in the industry, and is addressed to the man who is generally interested in oil production and not solely to the technologist. Using the minimum of technical language and virtually no mathematics, it sets out to show the prizes to be gained from the conservation of energy and reserves, the scientific facts which underlie the reasons for conservation and which form the basis of its practice, and the methods of operation to be adopted. It is in fact a complete outline of oil production, invaluable to the non-technical reader, but so authoritative in its handling that the technologist also will find its perusal of the greatest use.

As has been said the book is the work of a number of contributors. Normally such volumes lack a sense of unity and are unpleasant and trying to read. Such is not the case here, and the editor is to be heartily congratulated on the result achieved. Indeed, the style of writing is exceptionally good for a technical book. Scientific facts and arguments are presented without the too frequent use of technicalities; the easy flow and the ability to be clear without irritating the technologist are all deserving of praise.

In detail the subjects covered are: the elements of conservation; the oil and gas resources of the world; the nature of petroleum reservoirs and reservoir fluids; the fundamentals of oil recovery; the operation of reservoirs, including secondary recovery and pressure maintenance; and the legal questions involved. The last of these affects the U.S. reader only, but the others are universal in their scope, and are in no way limited by the fact that the illustrations and discussions are based on U.S. examples.

In brief, the book is highly recommended. P. D.

Pipe Resistance for Hydraulic, Lubricating and Fuel Oils and other Non-aqueous Fluids. T. E. Beacham. London: E. & F. N. Spon Ltd., 1951. Pp. 61. 18s.

The book is intended to provide a simple and accurate means of estimating pipe resistance for flow of oils, etc., by graphical methods and to avoid the laborious trial-and-error method of solutions of problems involving the correct choice of pipe diameter, etc., for given flow rates. For this purpose a series of twenty "Pipe Resistance Diagrams" have been prepared in which for three main pipe materials (drawn tube, steel, and W.I. pipe, and galvanized pipe) and for a variety of oils the pipe resistance in p.s.i/ft can be read as a function of the flow in Imp. gal/min, and bore of pipe in inches. In order to use the diagrams the necessary conversion factors from centistokes to Redwood No. 1 and Saybolt universal are tabulated, and variation of viscosity with temperature for a wide variety of industrial oils is illustrated graphically. Each resistance diagram is given for an oil of particular sp. gr. but the conversion of the result to an oil of different sp. gr. is a simple multiplication by the ratio of the sp. grs.

The diagrams are introduced by a short chapter on the method of use and on practical considerations illustrated by several worked examples. An appendix gives the method by which the diagrams have been constructed and curves for calculating the friction factor in the Darcy equation for various pipe roughnesses. Loss coefficients for pipe fittings are included. The book should prove of considerable value to design and petroleum engineers. F. M.

Synthetic Resins and Allied Plastics. Ed. R. S. Morrell. Third Edn. Ed. H. M. Langton. London: Oxford University Press. Pp. xvii + 747. 50*s*.

This work was first published in 1937, went into a second edition in 1943, and is now presented in a greatly extended form. Dr Morrell, to whom the original scope and design are due, died in 1946. The present editor has gathered together a team of fourteen collaborators and has worthily carried on the high traditions inherited from his predecessor. A very considerable amount of new matter has been contributed, notably in the case of protein and cellulosic plastics, alkyd resins, petroleum hydrocarbon and rubber resins, shellac, and electrical testing and requirements. New developments in manufacturing technique are discussed specially with reference to the fluorocarbons and the silicones. Of special interest to members of the Institute of Petroleum is the chapter on petrochemicals, which is concerned with the vast quantities now available through the cracking of petroleum, of highly reactive hydrocarbons capable of polymerization and condensation.

It is to be hoped that this very informative chapter may be considerably increased when the next edition is called for. Some idea of the scope of this truly encyclopædic work can be gleaned from glancing through the various section headings: Protein and cellulosic plastics; phenol formaldehyde resins; amino resins; vinyl resins; acrylic resins; coumarone and indene resins; ester gums; phenolic varnish and lacquer resins; alkyd resins; petroleum hydrocarbon and rubber resins; shellac; problems of resinification; electrical testing requirements; methods of identification and testing. Of special merit is the general introduction by the editor. This extends over sixty-four pages, and is extremely well documented. As a comprehensive survey of the subject it is worth very serious study and consideration.

The book is well illustrated, tabular matter, diagrams, and formulæ are excellently displayed, thoroughly complete indexes are provided, and the general presentation and typography are characteristic of the high standard in production set by the Oxford University Press. A. E. D.

Statistical Summary of the Mineral Industry. Production, Imports and Exports 1944–1950. Colonial Geological Surveys. London: H.M.S.O., 1952. Pp. 342 + iv. 25*s*. net.

The Mineral Resources Division of the Colonial Geological Surveys has performed a valuable service in bringing together between two covers such a wealth of statistical information on the world's mineral industry. For the seven-year period 1944–50 comprehensive details are given in alphabetical order of the mineral production, imports, and exports. Under each item the country entries are listed under "British" and "Foreign" headings.

The section on Petroleum and Allied Products occupies thirty-seven pages, and production details are given for crude petroleum, natural gasoline, natural gas, natural asphalt, asphalt rock, and oil-shale. Then follows a table occupying nearly six pages and covering refinery production in various countries. The remainder of the section is devoted to figures of exports and imports by countries and products.

This publication should prove a valuable source of information to anyone who wishes to have reliable figures for comparison purposes. All figures, except for natural gas, are in long tons. G. S.

ADDITIONS TO THE LIBRARY

Table of Dielectric Constants of Pure Liquids. A. A. Maryott and E. R. Smith. Washington, D.C.; U.S. Government Printing Office, 1951. Pp. 44 + iv. 30c.

This tabulation is National Bureau of Standards Circular 514. The "static" dielectric constants of more than 800 substances in the liquid state were critically examinated and tabulated in concise form. The table consists of three sections: (*a*) standard liquids; (*b*) inorganic liquids; and (*c*) organic liquids. An indication of the probable accuracy of the data is given. Wherever feasible, a simple analytical function is employed to express the variation of dielectric constant with temperature.

I.C.I. Engineering Codes and Regulations. Group A, Vol. 1–5.—Railways and haulages (Operation and maintenance). Pp. 21. Group A. Vol. 1–6. Road transport of engineering plant and materials. London: Imperial Chemical Industries Ltd., 1951. Pp. 19.

Available to the public through the Royal Society for the Prevention of Accidents.

The Pliocene Bryozoa of the Low Countries and their Bearing on the Marine Stratigraphy of the North Sea Region. R. Logaaij. *Presented by the author.*

Sulphur Poisoning of Nickel Catalysts. C. H. Riesz, H. A. Dirksen, and W. J. Kirkpatrick. Chicago, Ill.: Institute of Gas Technology, 1951. Pp. 24. $2.50.

This Research Bulletin No. 10 of the Institute of Gas Technology concerns the poisoning of catalysts used for gas manufacture by sulphur in the hydrocarbon feed stocks. The investigation was in two phases, the first to determine the effect of chemical composition of the sulphur compound, and the second to determine whether the problem could be solved by using a "sulphur-active" catalyst.

Expansion Behaviour of Coal during Carbonization. O. P. Brysch and W. E. Ball. Chicago, Ill.: Institute of Gas Technology, 1951. Pp. 60. $5.00.

This is Research Bulletin No. 11 of the IGT and by a critical review of literature and practice it discusses coal carbonization and recommends a research programme designed to establish the expansion behaviour of coal during carbonization. Literature references number over 200.

Bibliography of Books and Published Reports on Gas Turbines, Jet Propulsion, and Rocket Power Plants. E. F. Fiock and C. Halpern. *NDS Circular* 509. Washington, D.C.: U.S. Government Printing Office, 1951. Pp. 64. 20 cents.

An extremely valuable list of books (1910–50 inclusive) and published reports (1940–50 inclusive). References are grouped under subject headings, and all aspects are included.

Capital Formation in the Petroleum Industry. F. G. Coqueron and J. E. Pogue. New York: Chase National Bank, 1952. Pp. 39.

A summary covering 1934–50 of the data published annually under the title of "Financial Analysis of Thirty Oil Companies." Some figures have been revised, and several new features introduced.

British Standards. British Standards Institution:

B.S. 855 : 1952. Welded Steel Boilers for Hot Water, Central Heating, and Hot Water Supply. Pp. 50. 6*s.* net, post free.
B.S. 978 : 1952. Gears for Instruments and Clockwork Mechanisms. Part I: Involute spur, helical and crossed helical gears. Pp. 10. 2*s.* 6*d.* net, post free.
B.S. 1790 : 1952. Length Bars and Accessories. Pp. 22. 3*s.* net, post free.

THE INSTITUTE OF PETROLEUM

NOTICES, APRIL 1952

ENTRANCE FEES AND SUBSCRIPTIONS

The current Entrance Fees and Annual Subscriptions for membership of the Institute are :

	Entrance Fee	*Annual Subscription*
	£ s. d.	£ s. d.
Members and Fellows	2 2 0	4 4 0
Associate Members and Associate Fellows .	1 1 0	3 3 0
Student Members	Nil	1 1 0

APPLICATIONS FOR MEMBERSHIP OR TRANSFER

The following have applied for admission to or transfer of membership in the Institute. In accordance with the By-laws, the proposals will not be considered until the lapse of at least one month after the publication of this *Journal*, during which time any Fellow, Member, Associate Fellow, or Associate Member may communicate by letter to the Secretary, for the confidential information of the Council, any particulars he may possess respecting the qualifications or suitability of the candidate.

The object of this information is to assist the Council in grading the candidate according to the class of membership.

The name of candidates' proposers and seconders are given in parentheses.

Application for Membership

BAGGRIDGE, Malcolm Thomas, student apprentice, National Oil Refineries Ltd. (*E. J. Horley ; G. Davies.*)

BOULTON, Harry, operator, Bahrein Petroleum Co. Ltd. (*A. F. Pyrah ; P. Simkins.*)

BRADLEY-KIDD, Milton, production equipment engineer, Trinidad Leaseholds Ltd. (*A. S. Curlet ; J. W. Hardy.*)

CARR, Stanley John, Flight Lieutenant, Royal Air Force. (*A. Gill ; D. W. Tambling.*)

CLARKE, Jocelyn Allan Robin, petroleum engineer, Bahrein Petroleum Co. Ltd. (*R. Godfrey ; P. Simkins.*)

COWING, George, chemist, Messrs. James Arnott & Sons Ltd. (*L. Mills ; N. C. F. McCarthy.*)

COX, Albert Glyn, student apprentice, National Oil Refineries Ltd. (*E. J. Horley ; G. Davies.*)

CULLINAN, George Henly, general manager, Shell Chemicals Ltd. (*J. M. Butler ; F. Mackley.*)

CUNLIFFE, Brian William Port, student apprentice, National Oil Refineries Ltd. (*E. J. Horley ; G. Davies.*)

DANIELS, William Lionel Colin, Staff Captain, R.A.S.C. (*G. Reid ; R. H. Vernon.*)

DUNN, Gordon, draughtsman, Anglo-Iranian Oil Co. Ltd. (*R. C. Thomson ; W. Y. Ross.*)

FRANCIS, Daniel Norman, student apprentice, National Oil Refineries Ltd. (*E. J. Horley ; G. Davies.*)

GEEN, Eldred David, student apprentice, National Oil Refineries Ltd. (*E. J. Horley ; G. Davies.*)

GERMAN, William Richard, garage and service station business manager, Messrs. W. L. German & Co. (*C. Chilvers ; T. W. Wilden.*)

GILES, Donald George, administrative superintendent, Anglo-Iranian Oil Co. Ltd. (*C. E. Evans ; G. Sell.*)

GILLETT, Harry William, chemist, Kuwait Oil Co. Ltd. (*W. P. P. Hodgson; G. Elias.*)

GODFREY, Edward Grimmett, director, Universe Petroleum Co. Ltd. (*R. H. Reed ; C. A. Kemp.*)

GRANT, William John, refinery manager, Messrs. Berry Wiggins & Co. Ltd. (*R. C. Paterson ; J. H. Smith.*)

GRIFFITHS, Ronald, student apprentice, National Oil Refineries Ltd. (*E. J. Horley ; G. Davies.*)

HOLLAND, Richard Alan, student apprentice, National Oil Refineries Ltd. (*E. J. Horley ; P. F. Ellis.*)

MAINWARING, Alan Hugh, student apprentice, National Oil Refineries Ltd. (*E. J. Horley ; P. F. Ellis.*)

MILNER, Richard, In Charge American Purchasing Section, Kuwait Oil Co. Ltd. (*J. L. Elliott ; L. D. Scott.*)

MULHOLLAND, Bennett Douglas, estimator (Engineering Development), National Oil Refineries Ltd. (*I. Cameron ; E. J. Horley.*)

NORMAN, John, student apprentice, National Oil Refineries Ltd. (*P. F. Ellis ; E. J. Horley.*)

O'CONNELL, Guy James, sales engineer, Kellogg International Corp. (*J. E. Lytle ; J. W. Jewell.*)

OGDEN, Leslie Frank Sinclair, refinery mechanical engineer, Commonwealth Oil Refineries Ltd. (*E. W. Shell ; G. Peace.*)

PAYNE, Francis Gordon, student apprentice, National Oil Refineries Ltd. (*E. J. Horley ; G. Davies.*)

PRICE, William Henry, buyer, Shell Petroleum Co. Ltd. (*H. de Wilde ; C. Crossland.*)

RUDLING, Alan Thomas, staff operator, Bahrein Petroleum Co. Ltd. (*A. F. Pyrah ; P. Simkins.*)

SHEARN, Derek Bourne, student, University of Birmingham (*F. H. Garner ; F. Morton.*)

STIFF, William James, engineer, Iraq Petroleum Co. Ltd. (*D. B. Bremner ; A. F. Price.*)

WIGGINS, Robert George, relieving refinery operator, National Oil Pty. Ltd. (*G. E. Mapstone ; J. S. Durham.*)

Transfers

ANDREWS, Douglas, inspector (Petroleum and Explosives), London County Council. (*J. L. Ainsworth ; S. G. Burgess*) (*Associate Member to Member.*)

CUNNAH, Edward, managing director, Falcon Oil Co. Ltd. (*R. Macdonald ; G. M. Davies*) (*Associate Member to Member.*)

DUEGAN, Bhim Sain, senior scientific officer, Ministry of Defence (India). (*F. H. Garner ; F. Morton*) (*Associate Fellow to Fellow.*)

GIBSON, David Stuart, field chemist, Trinidad Petroleum Development Co. Ltd. (*N. P. Skerrett ; J. S. Collcott*) (*Associate Fellow to Fellow.*)

GREEN, Roy Clement, development assistant, National Oil Refineries Ltd. (*E. J. Horley ; P. F. Ellis*) (*Student to Associate Fellow.*)

HOWGILL, Donald Robert, deputy to chief engineer, Shell Petroleum Co. Ltd. (*E. J. Sturgess ; F. Mackley*) (*Member to Fellow.*)

MACDONALD, Ralph, director, Falcon Oil Co. Ltd. (*E. Cunnah ; G. M. Davies*) (*Associate Member to Member.*)

MORLAND, John, consulting engineer, Messrs. Geo. Wimpey & Co. Ltd. (*H. E. F. Pracy ; A. Crossfield*) (*Member to Fellow.*)

PEPPER, Albert Cecil, company director, Messrs. Alexander Duckham & Co. Ltd. (*S. J. M. Auld ; W. Kay*) (*Member to Fellow.*)

SHAWYER, Adrian Charles, Flight Lieutenant, Royal Air Force. (*E. J. Jenkins ; B. R. Bergin*) (*Associate Member to Associate Fellow.*)

NEW MEMBERS

The following elections have been made by the Council in accordance with the By-laws.

Elections are subject to confirmation in accordance with the By-laws.

As Fellows

MURPHY, D. G. NEPPE, S. L.

As Members

COLWELL, S. D. HOBSON, P. C.
GRIEVE, T. R. PEAKE, T. J.

As Associate Fellows

BLIGHT, N. B. KERNER, H.
BRODIE, C. E. KIRKALDY, P. H. S.
CANTRELL, T. L. MOORE, H. C.
DUNN, S. R. WILLIAMSON, W. R.
KAYE, A. H.

Transferred from Students to Associate Fellows

DOD, G. F. HOLLYMAN, H. C.
PALMER, J. S.

As Associate Members

KOCKX, M. J. A. THIRTLE, C. H. H.
WALSH, A. L.

Transferred from Student to Associate Member

HOWE, H. G.

As Students

BULLOUGH, J. E. GILL, J. C.

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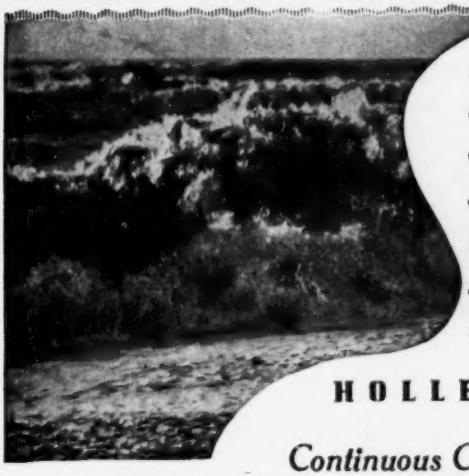

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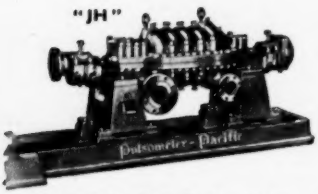

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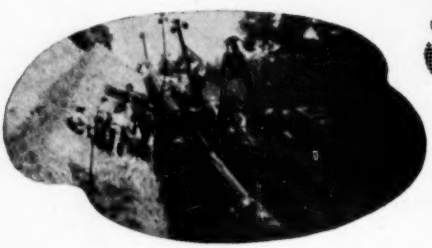

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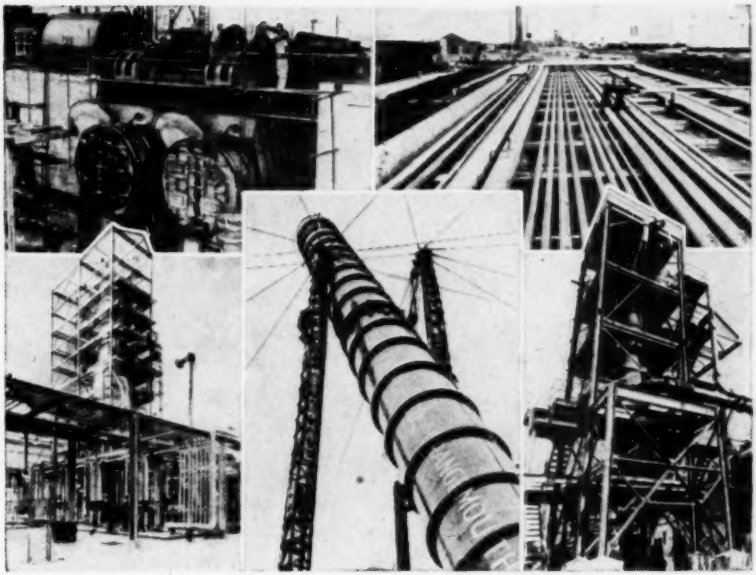

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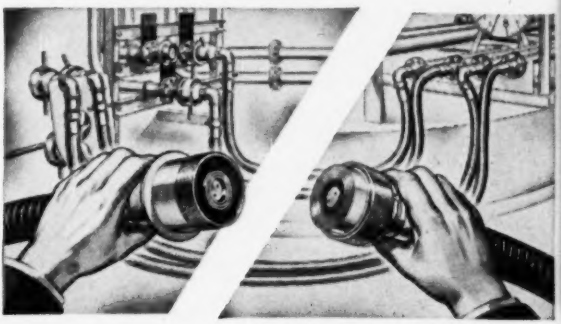

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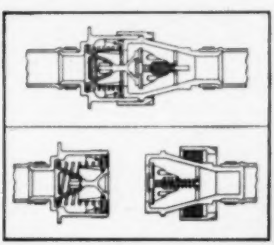

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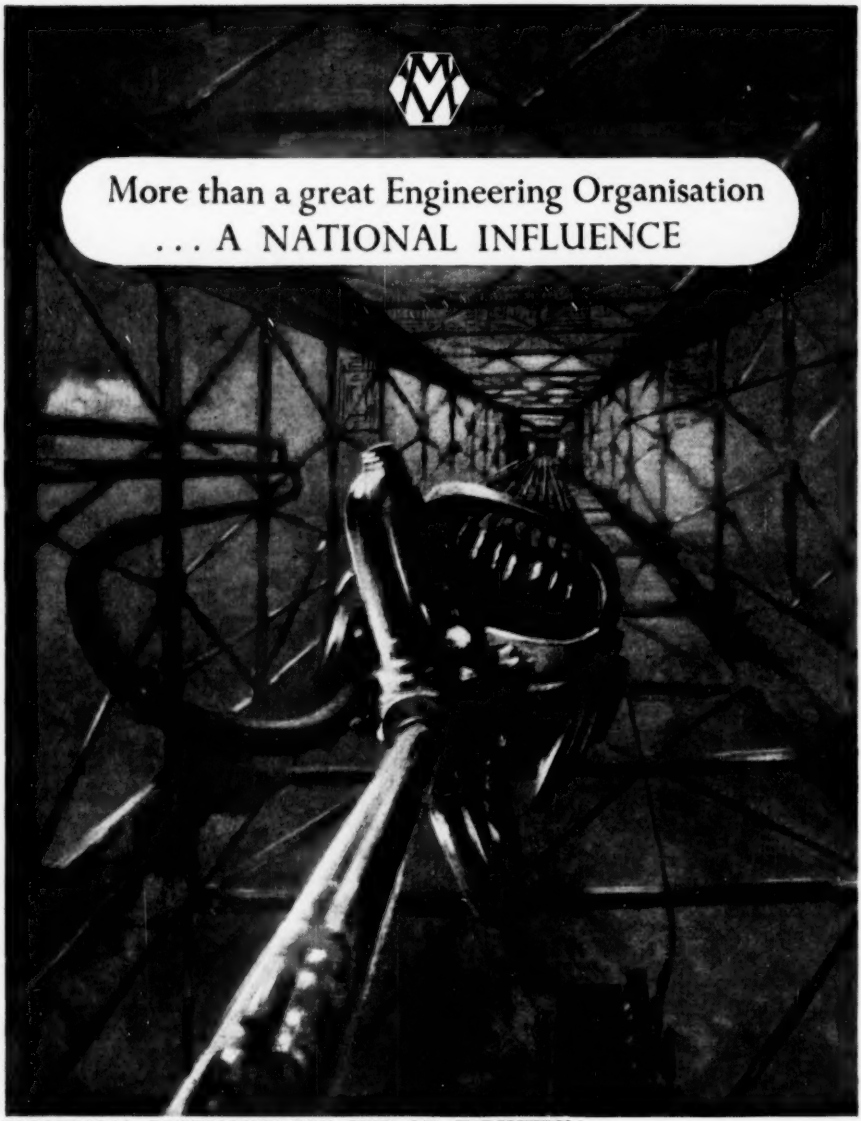

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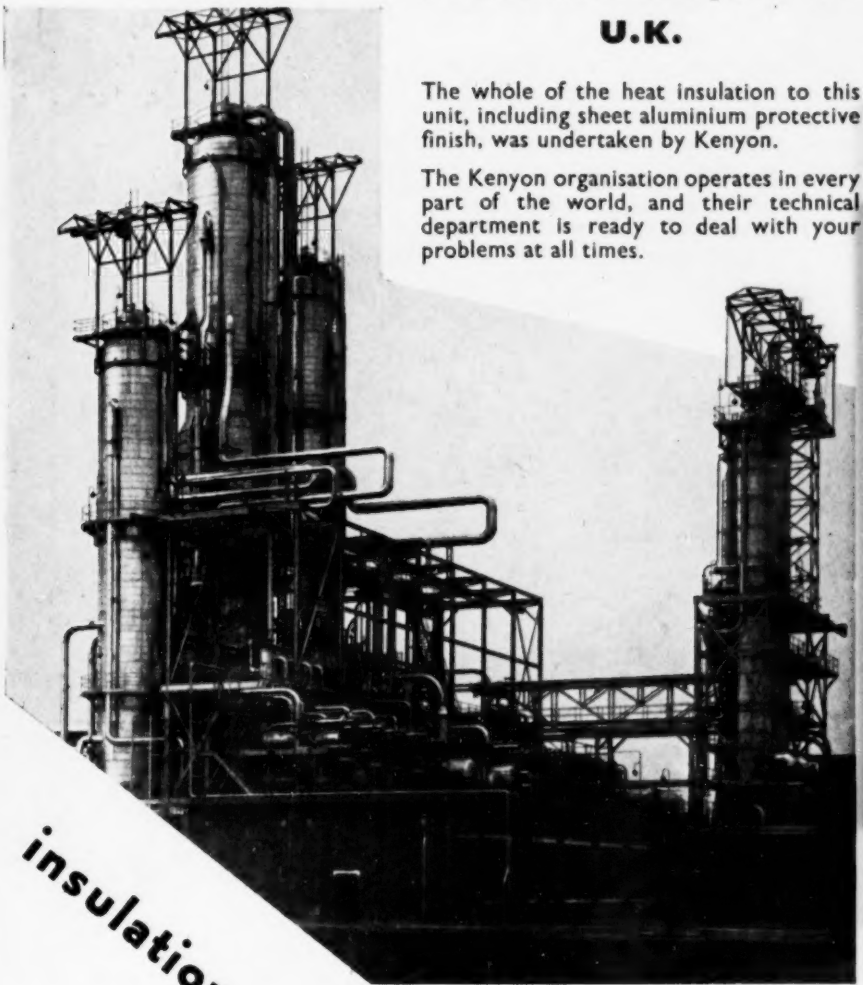

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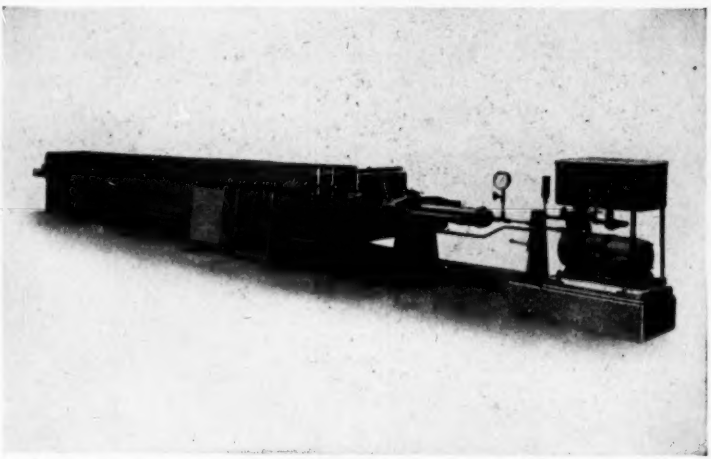

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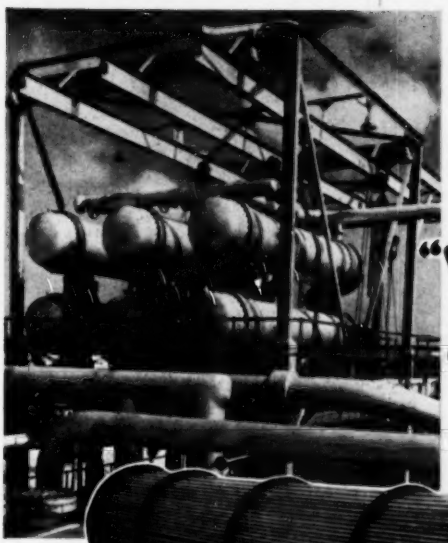

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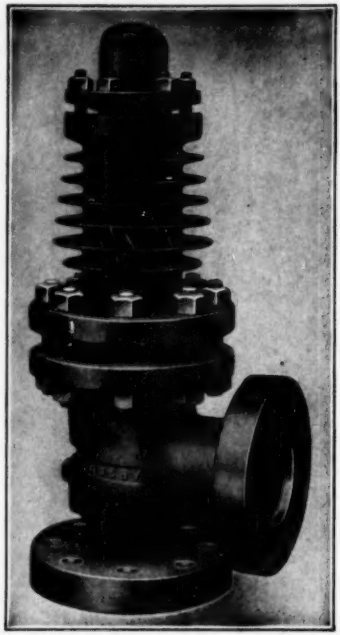

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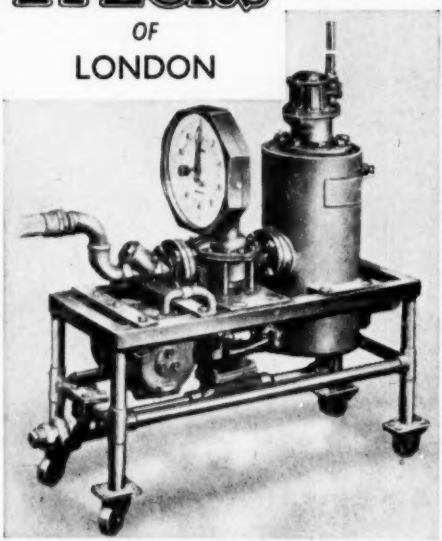

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